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THE STATEMENT OF ESSENTIAL HUMAN RIGHTS BY REPRESENTATIVES OF THE PRINCIPAL CULTURES OF THE WORLD

WILLIAM DRAPER LEWIS

Director, American Law Institute

(*Read November 18, 1944*)

IN the spring of 1942 The American Law Institute decided to ask a group of persons representing as many of the different cultures of the world as possible to report how far they were in agreement on those rights which were essential to individual freedom.

The American Philosophical Society contributed $5,000 towards the expenses of the proposed work as did also the Carnegie Foundation for International Peace and the Commonwealth Fund.

Collecting in the United States a group representing the great majority of the world's cultures was not an easy task. The Committee consisted of twenty-four persons; of these ten were United States citizens, the others represented the Arabic, Austrian, British, Canadian, Chinese, French, pre-Nazi German, Italian, Indian, Latin American, Polish, and Spanish. There was no representative of Russia in the sense that none of the members was at the present time a Russian citizen with complete knowledge and sympathy with the Soviet system. We had, however, on the Committee Kenneth Durant, an American citizen familiar with Russian conditions and the director of Tass, the Russian News Agency in this country. The reason we could not get the type of Russian we desired was that there were none in this country. At present, all educated Soviet Russians now here in full sympathy with the Soviet system are government officials.

The work of the Committee extended over eighteen months. Perhaps the best way to explain what the Committee did is to quote from their report to the Council of The American Law Institute. They say:

> The object of our appointment was to ascertain if we could agree on rights essential to the freedom of the individual and, if so, frame a statement of such rights.
>
> The accompanying draft (Statement of Essential Human Rights) is the result of several conferences each lasting two or three days supplemented by many meetings of subcommittees.
>
> The attempt has been to state what all democratic peoples would regard as the essential governmental safeguards of individual freedom. . . .
>
> It is outside the specific task you have assigned us to consider or recommend the use that might be made of this statement of rights. We have expressed them in such form that they could be adopted as a declaration of principles by an international organization, universal or regional, and also so that they could be incorporated in the constitutions of national states.
>
> We believe that in these articles we have defined the essentials of individual freedom with sufficient particularity to serve as a basis and a test of any plan for the postwar world. Whatever plan is drawn, the ultimate test of its wisdom will be whether it does or does not protect and promote individual freedom.

The Statement of Essential Human Rights made by the Committee is divided into eighteen articles. The first five represent freedom of religion, opinion, speech, the right to assemble, and the right to form associations. The sixth relates to freedom from wrongful interference with a person's home, reputation, privacy, activities, and property; the seventh to fair trial, combining the principal protections found in our Federal Constitution in regard to persons charged with a criminal or civil offense. The eighth article deals with the freedom from arbitrary detention provided for in our Constitution; the ninth provides that no one shall be convicted of crime except for violation of a law in effect at the time of the commission of the act charged as an offense, nor be subjected to a penalty greater than that applicable at the time of its commission. All these articles relate to matters already protected not only in our Federal Constitution but in the constitutions of nearly all the democratic countries of the world.

Most of the remaining articles are new to constitutions in this country. The tenth, one that relates to property rights, recognizes that to be free man must have the right to acquire, use, and dispose of a large variety of things. It would violate the article to prevent all or nearly all pri-

vate ownership; but it would not prevent the adoption of the present Soviet system as expressed in its Constitution which declares that private property cannot exist in production goods; that is, things on which persons are employed to produce other goods to be sold for the profit of the employer. This limitation is the cornerstone of the Soviet economic system; making as it does the government the producer of almost everything.

From the point of view of the citizen of the United States, the principal innovation is the introduction of five articles (Articles 11–15) which for lack of a better name we can call "social articles"; that is, the right to an education, the right to work, to reasonable conditions of work, to adequate food and housing, and to social security. I shall refer to these again.

There is also an article, Article 16, which declares that "Every one has the right to take part in the government of his state" and that "the state has a duty to conform to the will of the people as manifested by democratic elections." This article introduces the idea that the right to live in a democracy is essential to freedom, though a democracy as defined in the article would not necessarily exclude a king who attained his office by inheritance provided the people expressing their opinions in free elections determined the main lines of government policy.

Article 17 declares that "every one has the right to protection against arbitrary discrimination in the provisions and application of the law because of race, religion, sex, or any other reason." This article makes more explicit what is in great part achieved in our Federal Constitution by the statement that no person shall be denied the equal protection of the law. Nevertheless, the article does not carry out the desire for equal economic opportunity in private employment which today is the most insistant desire of negroes in the United States, though doubtless many of the members of the Committee, especially those not United States citizens, would have voted to insert such provision.

There is inserted in almost every article the correlative duty of the state. Sometimes this correlative duty cannot be specifically pointed out. But when we read Article 3 "Freedom of Speech" we find that "the state has a duty to prevent denial of reasonable access to channels of communication," as for instance, the radio where the possibilities of use are physically limited, the state must exercise its controlling or regulating power to insure the individual such opportunity of use as is practicable.

The comment to each article states the number of national constitutions in which analogous provisions are found. It will be doubtless a surprise to many citizens of the United States to know how numerous are the individual rights not found in our Federal Constitution, that are expressed in the constitutions of other countries. Thus, provisions similar to the proposed article on education are found in forty countries; provisions concerning social security are contained, generally in the form of social insurance, in the constitutions of twenty-seven countries.

Agreement as to essential human freedoms is one thing; their enforcement is another. The Institute's committee did not deal with enforcement. There are three main methods of approach to the enforcement problem. One is "court enforcement." It involves the enforcement of the right by courts in the ordinary administration of justice. This system is in operation throughout the United States.

The second system is the court system as modified by the administrative power to suspend constitutional guarantees of individual freedom in time of danger. When the first amendments to out Federal Constitution were adopted in the 'nineties of the eighteenth century, they constituted the first embodiment in a constitution of many of these individual freedoms. As the nations to the south of us threw off Spanish domination they too adopted constitutions which contained more or less similar statements of individual freedoms found in our Federal Constitution, and they also enforced the rights by court action in much the same way as we do. But the countries were disturbed by revolutions and the "man on horseback" often found it convenient to suspend constitutional guarantees, not only in time of violent commotion but often in a time of comparative quiet. In other words the appreciation of the constitutional guarantees of individual freedom are decreased by the frequency of the "administrative suspension of these rights." The results of this method varies with the political condition of the country. In some there is little recognition and enforcement of many of the essentials of individual freedom; in others there is a very wide recognition and enforcement.

The third system is that most familiar to us in the Declaration of Independence where it is said that "We hold these truths to be self-evident,

that all men are created equal, that they are endowed by their Creator with certain unalienable rights, that among these are Life, Liberty and the Pursuit of Happiness." Though the Declaration was adopted by the representatives of the colonies there was no thought of its being made a part of the Constitution of the subsequently inaugurated Federation. The Declaration of Independence is not a law but it is a declaration on the part of representatives of the Colonies severing their connection with Great Britain, of at least some of the fundamentals of human freedom. A similar document is the French Declaration of Right of 1791. This is a statement of principles, made by the representatives of the nation. Those who made it thought it should guide the legislative and administrative acts, but it is not itself law. If subsequently the legislature enacts a provision clearly contrary, nevertheless, the provision, until repealed is law. This does not mean however that this third system is ineffective. The solemn declaration of representatives of a nation of the fundamentals of individual freedom may, and in the long run usually has, a profound effect on law. While today, 168 years after the adoption of the Declaration of Independence, all men in the United States are not equally free, neither do they have equal opportunity under law to life, liberty, and the pursuit of happiness, there has been a steady trend in that direction. We have done away with chattle slavery, while today all about us goes on the struggle for a greater degree of equality in economic opportunity.

Whatever way we seek to enforce essential human freedom, it is first necessary to obtain as clear an idea as may be of what essential individual freedom is. This first step is that alone which the Institute's committee was charged to take and that only in so far as they found themselves in accord. In effect the statement of Essential Human Rights says:

> These are essential human rights on which all except one of us agreed; none of us say they are all the essentials of human rights; many of us feel that some of the rights expressed should be carried further; we do not say how they should be made effective; we make no statement as to whether all or some should be incorporated in constitutions national or international and enforced by courts; or whether all or some should be expressed in a formal declaration intended as a guide to legislation but not in itself a law.

When the statement of Essential Human Rights was reported to the Council of the Institute there was a tendency to regard it as the first draft of a Bill of International Rights to be enforced by court action. This of course it was not. The members of the Committee had been asked to produce a statement of those essential freedoms on which they agreed. This they had done. It is true that many members of the Committee would have been glad to sign the statement as a first tentative draft of a Bill of Rights to be reexamined as to whether all the rights could be enforced under existing conditions in a constitution of an International State or League of Nations; but it would have been certain that several members would have regarded some of the rights, especially the social rights, as not suited for insertion as enforceable rights in such a document.

When the members of the Council realized what the document contained they also realized that the Institute could not wisely undertake to draft either a Statement of Essential Human Rights or an International Bill of Rights. Should they try to do either of these things the social rights would come up for discussion and their insertion or inclusion would become a question which in the United States would generate a political discussion, for which the Institute is unfitted. The Council therefore did the only thing they could do—print and distribute to the members of the Institute the report of the Committee thereby permitting individual members or others to use the statement in any way they thought fit.

To us as citizens of the modern world which is daily moving towards a more complete industrialization the insertion of the social rights as essential human rights presents a question of great practical moment.

When these social rights were first introduced by the subcommittee appointed to consider them, United States members of the Committee asked: how could such provisions as the right to work, to housing, be enforced by the only method to which the United States was accustomed to enforce the individual rights in the Constitution, that is, by court action? Did not these social rights for effective enforcement require both legislative and administrative action and large specific appropriations of money? Was not the government in these rights asked to do something for the individual, not merely to refrain from unreasonable limitations on his right to express his ideas or exercise his religious devotions. Therefore, though it was true that it was

the Committee's task to state the essentials of human freedom on which they agreed, and it was also true that they had nothing to do with enforcement, nevertheless, it was hard for the United States citizens on the Committee, brought up in a country where almost all the individual rights expressed in its Constitution are enforced by court action, not to let the possible non-enforceability of a right by court action affect their position as to whether it was an essential right. Nevertheless as the discussion proceeded, it became clear that they were concerned solely with whether any of the social rights proposed were rights essential to human freedom. Finally, all but one agreed that they were. Is this opinion right? Personally I think it is.

Human rights essential to freedom are not rights in a vacuum but rights in an existing world. At the end of the eighteenth century no one thought of inserting the right to work in our Constitution. The United States was then largely an agricultural community of land owners on the eastern seaboard. If a person did not wish to work or had not the opportunity to work in the settled communities for another at a wage which satisfied him, he could "go to sea," or engage on his own account in some other occupation; or he could move west and take up land of his own. The throwing out out of work of a large section of a community by the closing down of a manufacturing enterprise was unknown. True the wages of the recently arrived immigrant were far from sufficient but who in a position of any authority concerned himself with the freedom of the newly arrived immigrant? Today we have changed all that. The number of those engaged in manufacturing exceed those in agriculture. They are in large part wage workers. There are no longer frontiers promising much to the pioneer. We the people of the United States looked at as one great society have changed. We concern outselves more than our ancestors did in the economic plights of our fellow men; at least for those who are our fellow citizens because we believe such plights can be modified or entirely avoided. In view of these things all but one of the United States' citizens on the Committee were compelled to conclude as they looked on the world around them that social rights had as direct a bearing on freedom as the right to our own religious beliefs and political opinions. So they voted with the foreign members of the Committee though several would not have done so during the first days of the debate for the inclusion of the social rights.

This discussion and its outcome was to me by far the most interesting and illuminating feature of the entire work. It graphically illustrates the difference between our own day and that of the day when our Federal Constitution and its first amendments were formed. The founders were not more hard hearted than we are. They would have liked all men to have the opportunity to work under reasonable conditions, to obtain food, housing, etc.; to have an education and social security, but these things where the individual was poor were unattainable. The poor they would always have with them. To think of a society in which poverty did not exist was to draw an unattainable Utopia. Today with the great advance in machinery and in industrial organization we know that, barring war, enough can be produced to give to each a minimum that will satisfy the requirements of these social articles. How we should go about organizing our production is a matter of opinion. Some emphasize the benefits of a "capitalistic production," others would introduce in large measure socialistic ideas, but we all know that if we are eager to secure for each the rights set forth in the social articles in this Statement of Essential Human Rights, it can be done under most forms of economic organization.

In the preamble of the document the Committee says:

> Upon the freedom of the individual depends the welfare of the people, the safety of the state, and the peace of the world.
>
> In society complete freedom cannot be attained; the liberties of the one are limited by the liberties of others, and the preservation of freedom requires the fulfillment by individuals of their duties as members of society.
>
> The function of the state is to promote conditions under which the individual can be most free.
>
> To express those freedoms to which every human being is entitled and to assure that all shall live under a government of the people, by the people, for the people, this declaration is made.

If you believe these principles the next thing is to take some carefully worked out expression of human rights and see how far you agree with it.

Then and not until then make up your mind how best to obtain the practical enforcement of the rights. What today will make you a liberal or conservative is whether you place the social

rights in the list of essential human rights irrespective of whether you would insert them in constitutions provided you include them as indispensable things.

As Judge Learned Hand said in his address on the "Faith We Fight For":

> What do we mean when we say that first of all we seek liberty. I often wonder whether we do not rest our hopes too much upon Constitutions, upon laws and upon courts. These are false hopes; believe me, these are false hopes. Liberty lies in the hearts of men and women; when it dies there, no constitution, no law, no court can save it; no constitution, no law, no court can even do much to help it. While it lies there, it needs no constitution, no law, no court to save it.

ADDENDA

Since the foregoing article was written much has taken place: the meeting of the representatives of the great nations at Dumbarton Oaks, the Inter-American Conference on War and Peace Problems, in Mexico City, and the United Nations Conference on International Organization at San Francisco.

The suggestions for the proposed Charter of the United Nations agreed upon at Dumbarton Oaks did not contain any reference to individual rights. It was the effort of the members of the Committee which drafted the Statement of Essential Human Rights as well as several national organizations who sent representatives to San Francisco to correct the omission, although it was generally recognized that the conference could not make a detailed statement of Essential Human Rights or an International Bill of Rights. All those anxious to emphasize Human Rights in the Charter were much gratified at the final draft produced. Indeed, the treatment of the subject, in view of the character of the political organization set up could not have been more explicit. The following is a statement of the way in which the matter is handled in the proposed Charter. Human Rights are dealt with in eight places.

1. The Preamble contains among other matters the following declaration:

> WE THE PEOPLES OF THE UNITED NATIONS
> Determined * * * * *
> * * * * * * *
>
> To reaffirm faith in fundamental human rights, in the dignity and worth of the human person, in the equal rights of men and women * * * *
>
> To promote social progress and better standards of life in larger freedom, * * *
>
> To employ international machinery for the promotion of the economic and social advancement of all peoples, have resolved to combine our efforts to accomplish these aims.

2. The first Chapter of the Charter relating to "Purposes and Principles" in Article 1 states that the purpose is:

> * * * * * *
>
> 3. To achieve international cooperation in solving international problems of an economic, social, cultural, or humanitarian character, and in promoting and encouraging respect for human rights and for fundamental freedoms for all without distinction as to race, sex, language, or religion.

3. Chapter IV relating to the "General Assembly" in Article 13 declares:

> 1. The General Assembly shall initiate studies and make recommendations for the purpose of:
>
> (*b*) * * * * assisting in the realization of human rights and fundamental freedoms for all without distinction as to race, sex, language, or religion.

4. Chapter IX on "International Economic and Social Cooperation" states: * * * * * * the United Nations shall promote:

> (*a*) higher standards of living, full employment and conditions of economic and social progress and development.
>
> (*b*) * * * international cultural and educational cooperation;
>
> (*c*) Universal respect for, and observance of, human rights and fundamental freedoms for all without distinction as to race, sex, language, or religion.

5. Chapter X, "Economic and Social Council," in Article 62 states: The Economic and Social Council, "may make recommendations for the purpose of promoting respect for, and observance of human rights and fundamental freedoms for all."

6. Chapter X, "Economic and Social Council," in Article 68 provides that: "The Economic and Social Council shall set up commissions in economic and social fields and for the promotion of human rights and other commissions as may be required for the performance of its functions."

7. Chapter XI, "Declaration Regarding Non-Self-Governing Territories," in Article 73 declares that the members of the United Nations as shall have or assume responsibility for the administration of territories recognize the principle that the interests of the inhabitants are paramount and accept as a sacred obligation to

promote the well-being of the inhabitants of these territories and to this end:

* * * *

(*b*) to develop self-government, to take due account of the political aspirations of the peoples, and to assist them in the progressive development of their free political institutions, * * *

8. Chapter XII, "International Trusteeship System," in Article 76 provides that the basic objectives of the trusteeship system shall be* * *

(*c*) to encourage respect for human rights and for fundamental freedoms for all without distinction as to race, sex, language, or religion, * * *

It is gratifying to record that two members of the American Law Institute Committee were delegates to the San Francisco Conference and that several other members attended and joined with representatives of influential national organizations in working for the recognition of human rights. Undoubtedly, however, the recognition of the growing popular demand in many countries that "something should be done about the rights of individuals" was the potent factor.

When United Nations is organized one of the first acts of the Commission to be appointed by the Economic and Social Council will be the drafting of a detailed Statement of Essential Human Rights. Stettinius has indicated his intention to press for an International Declaration of Rights at the first meeting of the General Assembly, to include the economic rights as well as civil liberties. The draft of the Institute's Committee which is the only one written by representatives of the principal cultures of the world will naturally have an influence.

The draft is also being used by the Pan American Juridical Committee which as directed by the Conference in Mexico last March is drafting in Rio de Janeiro a Pan American Declaration of Rights.

AREOPAGITICA—1644

CHARLES G. OSGOOD

Professor Emeritus of English, Princeton University

(*Read November 18, 1944*)

JUST three hundred years ago this month—in fact, three hundred years ago this very minute—in a dark corner of London a hand-press was creaking and clanking in labor with this little pamphlet.[1] It is *Areopagitica: a Speech of Mr. John Milton for the Liberty of Unlicenc'd Printing, to the Parliament of England*, a declaration of human freedom which today reverberates in the hearts of men with deeper resonance than ever before in all these three centuries. It has therefore occurred to certain members of this Society for Promoting Useful Knowledge that we might fitly pause in this promotion long enough to note the anniversary and commemorate the event.

This little pamphlet, and the lesser tract on education, are the only single prose works of Milton, out of thousands of pages, to survive—that, is, of course, unpreserved in academic alcohol. Almost unnoticed in its time and for one-hundred and fifty years afterwards, the fame of *Areopagitica* has waxed greater and greater unto this latter day, when our liberties have again been impugned and defended at infinite cost of energy, blood, and treasure.

Areopagitica was but an episode in the struggle for freedom of speech, and that struggle but one sector in the long Battle for Toleration. Ever since the time of Mary Tudor laws requiring the censorship and registration of published books, designed to estop sedition and heresy, had been variously renewed and revised. And now, in 1644, the Presbyterians in Parliament, who had known right well what it was to suffer suppression under an intolerant episcopacy, were at last in the saddle. Taking their turn at intolerance, they passed an act of censorship of their own, to suppress all "false forged, scandalous, seditious, libellous, and unlicensed papers, etc., . . to the great defamation of religion and government." No sooner were they rid, with Milton's help, of their oppressors the bishops, than they too, to his utter disgust, clamped down on freedom of utterance. Hence Milton's pungent line, at once as witty and learned as any ever penned:

> *New Presbyter* is but *Old Priest* writ large.

For some time Milton had been a thorn in the side of authority. He had already defied the law requiring registration and license to publish, and without permit had hurled his four crushing broadsides upon the bishops. Now, in the same irregular way, he issued two tracts for divorce, to the general scandal. Yet no finger was laid upon him.

The year 1644 was a foaming whirlpool of pamphlet controversy in the struggle for liberty. Professor Haller, in his learned essay, *Before Areopagitica*, cites more than thirty pamphlets, including one by our own Roger Williams, which were issued before *Areopagitica* appeared in November. As he describes the storm:

> Limited at first to the question of church government, that controversy promptly became a controversy over freedom of thought and discussion. Limited at first to the question of a free pulpit, it became a question of a free press. Limited at first to the rights of clergymen in their ministerial interests, it became a question of the rights of all men in their various concerns, whether religious or secular. Such was the trend of the discussion which took place in the tracts on liberty which appeared in London between January and November, 1644.

After toiling vicariously through hundreds of these yellowing and forgotten pages, Professor Haller is able to tell us that Milton, three hundred years ago, had obviously trudged the same rugged path and picked up along the way much that he could and did use in fashioning this, his own towering masterpiece. For chiefly out of material rough-hewn by others before him was it created.

Though the "speech" was not intended for oral delivery, he chose the traditional, well-ordered form of the "deliberative" oration prescribed by Aristotle and Quintilian—Exordium, Statement of the Question, Digression, Argument, Refuta-

[1] A fine copy of the first edition, from the Princeton University Library, was on exhibition.

tion, Peroration. To this he adheres with a great artist's passionate worship of beauty of form.

He first, in the Exordium, engages the favorable attention of his audience, the Parliament. He then states the case. He then digresses in a memorable eulogy of books which has furnished certain well-worn sentences to adorn the walls of many a public library. Follows the fourfold argument:

1. An historical review of licensing from Athens down, "such a homily, as shall lay before ye, . . . the inventors of it to bee those whom ye will be loath to own."

2. Wise reading is uncensored reading. Bibliophobia is a foolish fear. "Prove *all* things," "To the pure all things are pure." "Knowledge, whether of good or evil . . . cannot defile, nor consequently the books, if the will and conscience be not defiled."

3. Censorship can do no good. Though it stop naughty books, it cannot stop a hundred other avenues to the soul—old books, other arts, social intercourse. Besides, your licensers are bound to be incompetent, since no man fully competent to judge a book will submit to the humiliating drudgery, the "tedious and unpleasing journey-work," of censorship.

4. Censorship does great and positive harm. It discourages and affronts learned men. It is the greatest indignity to a free and knowing spirit that can be put upon him. It insults the nation. It is hostile to the survival of Truth amid all freely uttered opinions.

Then, the magnificent Peroration, an apotheosis of England as the high exemplar of true liberty before a wistful and envious world. Happy she, even amid her turmoil, for God has chosen her first in whom to begin His reform of the very Reformation itself.

> Behold now this vast City; a City of refuge, the mansion house of liberty, encompast and surrounded with his protection! The shop of warre hath not there more anvils and hammers waking, to fashion out the plates and instruments of armed Justice in defence of beleaguer'd Truth, then there be pens and heads there, sitting by their studious lamps, musing, searching, revolving new notions and idea's wherewith to present, as with their homage and fealty the approaching Reformation; others as fast reading, trying all things, assenting to the force of reason and convincement. What could a man require more from a Nation so pliant and so prone to seek after knowledge? What wants there to such a towardly and pregnant soile, but wise and faithfull labourers, to make a knowing people, a Nation of Prophets, of Sages, and of Worthies?

Such is the faint dotted outline of Milton's grand proclamation. And now, after three centuries, what element of greatness, what power of survival, has thrust this little pamphlet up out of the moldering dust-heaps of discussion and wrangle, that we should be moved to commemorate it? Its argument, we see, is not original; it is not based on considerations of law, precedent, natural right, or philosophy. It is, simply, a protest against bibliophobia, a burning confession of faith that Truth unhampered will survive.

> Though all the windes of doctrin were let loose to play upon the earth, so Truth be in the field, we do injuriously by licencing and prohibiting to misdoubt her strength. Let her and Falshood grapple; who ever knew Truth put to the wors, in a free and open encounter. Her confuting is the best and surest suppressing.

Even so Milton could not quite keep pace with his most advanced contemporaries, for he would make at least one exception of

> Popery and open superstition which as it extirpates all religions and ciuill supremacies, so it self should be extirpat, provided first that all charitable and compassionat means be us'd to win and regain the weak and the misled.

The treatise, then, has obvious limitations. And another of these is Milton's egoism; for only when evil touched his own case, was his genius stirred to its terrific repercussions.

> Give me the liberty to know, to utter, and to argue freely according to conscience, above all liberties.

But his was genius large enough to include the general case and cause of mankind.

Areopagitica, then, is a great work of art, almost of poetry; for although conceived and uttered, as Milton would say, in the cooler element of prose, it rises near to the simple, sensuous, and passionate level of poetry. Into a traditional, beautifully proportioned mold he poured the matter of his mind and heart, plastic with feeling, for, "the very attempt of this addresse thus made, hath got the power within me to a passion," which "I now manifest by the very sound of this which I shall utter." Then, by the very name, *Areopagitica*, with its ancient connotation of Athenian eloquence and pristine justice, he clothes his whole fabric, as was his wont, in the

rich texture of allusion to "the old and elegant humanity of Greece."

Clearly, artist that he was, he knew what he was about.

What, then, has been the effect of *Areopagitica* on men's minds? Parliament was deaf to it. They neither withdrew, nor modified their odious Order. They bullied some obscure and helpless printers, but let Milton alone. Perhaps they took his giant measure, and realized what a sorry figure he might make of them to posterity, or they of themselves, if they attempted the impossible, and tried to subdue him.

Censorship continued and *Areopagitica* was forgotten for the rest of the century. In 1693 it was quoted by Charles Blount, who had seen one of his own tracts burned by the common hangman. In 1698 Mathew Tindal lifted various transcriptions from it without acknowledgment. Evidently, after fifty years the tract was no longer recognizable. It did not go into a second edition until 1738, almost a century after the first. That eminent disciple of Milton, author of the poem *Liberty*, James Thomson, was the editor, and the occasion was a new attempt to curb the stage by censorship, which involved in the opposition the conspicuous talents of no less than Henry Fielding and Lord Chesterfield. In 1779 Dr. Johnson paid his qualified respects to *Areopagitica*, saying:

> The danger of such unbounded liberty and the danger of bounding it have produced a problem in the science of Government, which human understanding seems hitherto unable to solve. If nothing may be published but what civil authority shall have previously approved, power must always be the standard of truth; if every dreamer of innovations may propagate his projects, there can be no settlement; if every murmurer at government may diffuse discontent, there can be no peace; and if every sceptick in theology may teach his follies, there can be no religion. The remedy against these evils is to punish the authors; for it is yet allowed that every society may punish, though not prevent, the publication of opinions, which that society shall think pernicious; but this punishment, though it may crush the author, promotes the book; and it seems not more reasonable to leave the right of printing unrestrained, because writers may be afterwards censured, than it would be to sleep with doors unbolted, because by our laws we can hang a thief.

So spake Dr. Johnson, for himself and his whole century, faith tempered by prudence, poetic imagination by common sense.

But in 1788 Mirabeau, in his essay *Sur la Liberté de la Presse*, confessedly adapted generous portions of *Areopagitica*, and lost none of its propulsive energy. Strange that this stirring manifesto of Milton's should have to lie mute and neglected half of these three hundred years, waiting for men to hear its call. The complacent eighteenth century, frowning on the memory of Cromwell and the Commonwealth, had no ear for its thunderous diapason. Only with the "romantic" awakening did men grow attuned to its larger cadence and grander import. Since Holt White's excellent edition in 1819, separate editions have progressively multiplied, partly under academic compulsion, I admit; yet none of them perfunctory.

Amid the hundreds of arguments on this subject of a free press to which the world has listened, many of them backed by reason and conviction equal to Milton's, what is it that raises *Areopagitica* to its dateless preeminence? Merely the accident of the author's great name? I think not —except that, uttered by a preeminent poet, in an hour when the subject "hath got the power within me to a passion," it has risen above all other discussion close to the altitude of great poetry, and has universalized the matter for all time. Let us give ear for a moment and see if this is mere prose:

> When a man hath bin labouring the hardest labour in the deep mines of knowledge, hath furnisht out his findings in all their equipage, drawn forth his reasons as it were a battell raung'd, scatter'd and defeated all objections in his way, calls out his adversary into the plain, offers him the advantage of wind and sun, if he please; only that he may try the matter by dint of argument, for his opponents then to sculk, to lay ambushments, to keep a narrow bridge of licencing where the challenger should passe, though it be valour anough in souldiership, is but weaknes and cowardise in the wars of Truth. For who knows not that Truth is strong next to the Almighty; she needs no policies, nor stratagems, nor licencings to make her victorious, those are the shifts and the defences that error uses against her power: give her but room, & do not bind her when she sleeps, for then she speaks not true.

What, then, in this year of grace 1944, is *Areopagitica* to us, more than a magnificent literary museum piece, fit, let us say, to be enshrined in such a noble sanctuary of liberty as that close at hand whose hem we touch? Our press is free, is it not, beyond peradventure?

Yes, free from civil censorship and interfer-

ence, except in the exigencies of war. But what of those subtler restraints and discouragements incident to a democracy—the restraints applied through the menace, or the wealth, or the influence, of big pressure groups, of newspaper chains from coast to coast (chains indeed!), of powerful advertisers, of bosses and their rings, of religious or professional organizations, of rich regents and arrogant trustees, of superpropaganda, of planned confusion, of radio control? More powerfully mobilized, more subtly disguised than ever, the captors of the human mind seem still to lie in wait. Yet amid these dangers we have grown sensitive, and jealous of our freedom. And by this token the soul-animating strains of Milton's trumpet voice should today vibrate in our ears and hearts with more authentic sound than in all the three hundred years now gone.

PITUITARY AND SEX HORMONES WHICH INCREASE PLASMA CALCIUM IN BIRDS AND MAMMALS

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ABSTRACT

The pituitary hormone which increases plasma calcium in doves, pigeons, and fowl is gonadotrophin, but it is not known whether the follicle-stimulating or luteinizing component is the effective substance. Gonadotrophin is effective in hypophysectomized or thyroidectomized adult female pigeons, but not in males or gonadectomized females. Marked or maximum serum calcium values are obtained only after prolonged daily dosage with gonadotrophin or estrogen. Estrogenic, but not androgenic, hormones have specific ability to increase the "bound" calcium in the blood of birds of both sexes; they are approximately equally effective in normal, hypophysectomized, castrate, thyroidectomized, and adrenalectomized pigeons.

Less extensive study failed to associate any pituitary hormone with ability to increase the plasma calcium in rats and rabbits. Estrogens did not clearly affect the level of plasma calcium of normal or parathyroidectomized rats. Under some conditions huge doses apparently increased the plasma calcium in some but not in all rabbits. Heavy doses apparently increased plasma calcium in inadequate tests made on five dogs.

This demonstration of a dissimilar action of the two types of sex hormones on the blood calcium is united, as was done in our preliminary report in 1936, with facts which indicate their unlike effects on the development of the skeleton in birds and mammals. The two groups of facts provide the basis for a unified view of certain sex differences encountered in medicine, sex research, and anthropology. That general view or theory is restated and discussed.

AT the end of 1936 we published (1) a rather extensive preliminary report upon the earlier results obtained in the present study. Data presented at that time showed that the pituitary hormone which increases plasma calcium in normal and hypophysectomized adult female pigeons—but not in castrates—is gonadotrophin; a year later it was clearly stated that gonadotrophin is almost or entirely ineffective in males (2). Typical data tabulated in our preliminary report (1) further showed that estrogens quickly and greatly increase the plasma calcium of castrate and hypophysectomized birds of either sex (a small increase was reported in dogs and rats), while androgens are entirely ineffective. Riddle and Reinhart (3) had previously shown that the plasma calcium in female pigeons is more than doubled concurrently with the growth of two ova in the ovary, and Kyes and Potter (4) had shown that the time of this development of the ova is likewise coincident with a calcification of medullary bone in pigeons; also, others had observed that estrogen induces both resorption of the pelves of rodents (5, 6) and precocious closure of the epiphyses of dogs (7). Those earlier observations were united with the newly found facts and made the basis for a general theory of the role of the sex hormones in the skeletal development of animals and man (1). That theory soon received strong support from studies which showed conclusively that estrogens exert a specific action both on bone formation and bone resorption in many species of birds (8–13) and mammals (14–18). The weakest point in the theory was, and still is, the conflicting evidence of ability of estrogen to increase the plasma calcium of mammals. The present paper presents the complete results of our prolonged study of these subjects.

Earlier data from other laboratories had provided some evidence that a product of the anterior pituitary is capable of increasing the blood calcium, and it was usually thought that this substance ("parathyrotrophic" hormone)

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stimulated the parathyroids. Hoffmann and Anselmino (19) reported that whole pituitary extracts increased the blood calcium of two dogs and ten rats. In a single dog injected with extract of sheep pituitary for ninety days Thompson and Cushing (20) reported that the serum calcium values remained consistently higher than those of the control animal. Shapiro and Zwarenstein (21, 22) observed that a crude anterior lobe extract raised, while a posterior lobe extract lowered, the blood calcium of hypophysectomized and of ovariectomized toads. In anaesthetized cats Shapiro (23) observed that 1.0 cc. of commercial Antuitrin did not affect the level of serum calcium at four to five hours; but 2 or 3 cc. increased the calcium from 8.8 mg. per cent (control) to 12.4 mg. per cent. Marenzi and Gerschman (24) injected six dogs for six to eight days with crude anterior lobe extract and obtained an average value of 12.8 mg. per cent; from nine control animals the value obtained was 11.2 mg. per cent. In a preliminary study Friedgood (25) observed that a partly purified extract of anterior pituitary tissue gave a slight increase in the plasma calcium of rats and guinea pigs. Contrary results, however, had also been reported. Cannavo (26) observed no change in plasma calcium of humans and dogs injected with an extract rich in gonadotrophin. In normal and ovariectomized rabbits Hogben and Charles (27) noted that huge doses of saline extracts of fresh anterior lobes cause a slight temporary decrease in serum calcium from the fourth to the nineteenth hour. Dixon (28) injected a crude extract daily for five days into three rats; though their ovaries were luteinized their blood calcium was not changed appreciably. More recent results will be discussed later.

Earlier reports on the action of estrogens on the blood calcium were discordant and inconclusive. In 1927 Riddle (29) concluded that ovarian hormone, well known to be responsible for the cyclical growth of the oviduct, is probably also responsible for increases of Ca, P and fat which had then been observed at the egg production cycles of pigeons. Crude ovarian extracts were reported to decrease the plasma calcium of rabbits (30, 31), and slightly to increase that of cattle (32). Estrogen was reported by Dixon (28) to be without significant effect in rabbits, rats, and dogs; it is notable, however, that the blood calcium of each of the three dogs injected with ovarian extract was sustained slightly better than its control. In the female toad Shapiro and Zwarenstein (21) clearly showed that both hypophysectomy and ovariectomy lead to a significant decrease of the serum calcium. Mathieu and Barnes (33) gave small daily doses (100–300 R.U.) of theelin or theelol to two normal and four parathyroidectomized dogs. Apparently they examined the blood of these dogs only at ten or more days after starting the injections; at that time the calcium was unaffected in the normal dogs and decreased in the operated dogs. Foley (34) reported that heavy short-term doses of pure estrogens induce a temporary fall in the serum calcium of lactating cows. Saviano (35) repeatedly observed an increase in the plasma calcium of two male dogs injected over a period of a few days with Progynon. Much of the recent literature has been reviewed by Riddle (36) and by Campbell and Turner (37). Some significant recent studies on this topic will be discussed later.

MATERIAL AND METHODS

All animals, except some hypophysectomized pigeons (which consume a minimum of food) and several groups of rabbits, were subjected to a short fast before blood samples were drawn. Pigeons, doves, fowl, rats, and rabbits were fasted for twenty to twenty-four hours; dogs for fifteen to seventeen hours. Daily injections (seven per week) were made intramuscularly into birds and subcutaneously into rats and dogs. Rabbits frequently refused to eat during several days following a first injection of certain pituitary preparations. The routine diet of the several types of animals was not otherwise modified for these tests. The exact age of all animals used was known, excepting only five dogs and nine adult fowl. Rats of Wistar strain, aged 4 to 5 months, and New Zealand White rabbits 3.5 to 10 months old, were used. Pigeons less than 3.5 months old are regarded as young; birds of 3.5 to 5 months are considered adolescent; adults are either birds that have produced eggs, or males more than 7 months old. Most of the pigeons used were White Carneaux, obtained from a reliable breeder in lots of twenty to forty at forty-two to forty-five days after hatching. In starting tests on such a lot of birds the calcium value from only five or ten of them was sometimes obtained and utilized as a control value for the entire lot. Such values, however, are placed in parentheses in the tabulated data.

Again, litter-mate rats were sometimes used to supply control for tested rats, but these cases also are specially designated by their enclosure in parentheses. Concerning control calcium values it should be noted further, that clear indications of seasonal variations were obtained and that measurements were made at all seasons and over a period of years. In view of the nature and variety of the tabulated material it seems obvious that little would be gained by calculations of standard errors for the values obtained. The significance or non-significance of most of the determinations is fairly evident; in other cases this can be judged by the extent to which the indicated differences are repeated in a series of similar tests.

Injections were started in nearly all operated animals not earlier than three days after operation. Most blood samples from rats were obtained by heart puncture; from all other animals the blood was obtained from superficial veins and without anesthesia. Heparin was used as anticoagulant and the samples centrifuged at once. More than 90 per cent of the determinations were made on plasma (1.0 cc. rat plasma was frequently accepted) by the method of Clark and Collip (38). The remainder of the determinations, limited to more recent samples from groups of estrogen-treated pigeons and rabbits, were made colorimetrically (Roe and Kahn, 39). Phosphorus was determined by the method of King (40), and protein nitrogen by micro-Kjeldahl.

Much experience demonstrates that a mere name applied to a hormone or extract of the anterior pituitary gland is an inadequate characterization of the substance or substances covered by the name. This laboratory prepared most of the pituitary preparations used here; a few preparations, properly designated in the tables, were obtained from others. On all of these preparations we have conducted very extensive assays (on pigeons, two-day chicks, and twenty-one-day rats). Though it does not seem advisable to publish the results of those assays here, the *numbers* of the several preparations used are indicated on the tables. Results of assays of some of these preparations (Nos. 380, 533, 542, 549, 576, 595H) have been published by Riddle (41); others (547R, 582, 626, IG352, BVP24A) by Schooley, Riddle, and Bates (42). For still other preparations (643, 781, 786) the results of routine assay, together with additional information on unlike effects on carbohydrate and fat metabolism, will be published elsewhere (Riddle and Opdyke, 43).

Since it was desirable to utilize various kinds of birds and mammals, also to test the action of a very large number of hormones and extracts—and indeed to test each hormone after quite different periods of dosage—only small groups of two to five animals (of each sex) were commonly used in individual tests. This fact makes it necessary to use a large amount of tabular matter in the presentation of the results of our protracted study of this subject. In these tables, however, the data obtained from uniform tests of the two sexes have been combined in all of those cases in which little or no sex difference was apparent. In order to reduce tabular matter to a minimum practically all of the data tabulated in our preliminary report (1) are omitted here. Likewise several short-term tests (under four days) made on birds with pituitary hormones are omitted; these particular results were all negative for a reason which is made evident by the data actually presented.

EXPERIMENTAL RESULTS

THE PITUITARY HORMONE WHICH INCREASES PLASMA CALCIUM IN BIRDS

The data on this topic are given in table 1. Preparations rich in gonadotrophin and thyrotrophin (and practically free of prolactin and corticotrophin), when injected daily for ten to fourteen days, regularly increased the plasma calcium of adolescent female pigeons, and of hypophysectomized adult female pigeons. These same preparations, injected for seven to twelve days, caused no significant change in the plasma calcium of male pigeons and of young female pigeons. In ovariectomized adult pigeons and fowl there was also no effect from injection for seven days. Since mare serum is rich in gonadotrophin, but free from thyrotrophin, the results obtained with it are very important because they indicate that gonadotrophin, not thyrotrophin, was the effective pituitary factor in the tests which have just been described. When injected for seven to eleven days mare serum markedly increased the plasma calcium of normal and hypophysectomized adult female pigeons; it had little or no effect in adult males. The concentrated extract of mare serum (Gonadogen) was used only at a single dose level (and for ten days), but it apparently caused a slight increase in the plasma calcium of a group of four hypophysectomized *young* females.

TABLE 1

PLASMA CALCIUM IN PIGEONS, DOVES AND FOWL AFTER DAILY INJECTIONS WITH PITUITARY AND OTHER HORMONES

Animals		Daily dosage		Mg. calcium per 100 cc. plasma					
Kind and sex	No.	Amount (mg. or units)	Term	Control	After various days of dosage				
					1	2–3	4–6	7–10	11–14
			days						
Gonadotrophin + thyrotrophin (Nos. 549, 630, 643, 730)									
Adolesc. ♀ pigeons	3	3.5 mg.	14	10.6					13.6
Adolesc. ♀ pigeons	3	5.0 mg.	10	10.2				12.6	
Adolesc. ♀ pigeons	1	3–10 mg.[a]	12	9.3				16.6	
Adolesc. ♂ pigeons	4	5.0 mg.	10	9.9				10.2	
Adolesc. ♂ pigeons	4	3–10 mg.[a]	12	10.3				9.9	10.2
Hypct. ad. ♀ pigeons	5	5.0 mg.	12	(9.3)				16.6	15.6
Thydct. ad. ♀ pigeons	2	5.0 mg.	6	11.3			19.4		
Thydct. ad. ♂ pigeons	4	5.0 mg.	6	9.9			9.8		
Hypct. ad. ♂ pigeons	6	4.0 mg.	7	9.4				9.2	
Young ♀ pigeons	3	3–10 mg.[a]	12	10.5				10.5	10.8
Young ♂ pigeons	3	3.0 mg.	7	9.9				10.6	
Young ♂ pigeons	2	10.0 mg.	12	(9.1)		9.3			8.8
Spayed ad. pigeons	2	10.0 mg.	7	10.0				10.4	
Spayed ad. hens	4	20.0 mg.	7	12.5				12.4	
Mare serum (Parke, Davis)									
Hypct. ad. ♀ pigeons	2	0.4 cc.	11	9.8			11.7		18.5
Adult ♀ pigeons	3	1.0 cc.	7	11.3				16.3	
Hypct. ad. ♀ pigeons	4	0.4 cc.	10	9.9				13.9	
Adult ♂ pigeons	2	1.0 cc.	8	10.3			10.7	11.0	
Hypct. ad. ♂ pigeons	3	0.4 cc.	10	9.8			9.2	10.4	
Gonadogen (Upjohn)									
Hypct. yg. ♀ pigeons	4	2 units	10	(9.3)				11.2	
Hypct. yg. ♂ pigeons	3	2 units	10	(9.1)				10.6	
Whole anterior pituitary extract (Nos. 251, 542, 547R, 582)									
Hypct. ad. ♂ ♀ pigeons	4	15.0 mg.	10	9.9				10.1	
Hypct. yg. ♀ pigeons	4	10.0 mg.	10	9.5				9.9	
Young ♂ ♀ pigeons	6	10.0 mg.	10	(9.7)				11.1	
Hypct. yg. ♂ ♀ pigeons	10	20.0 mg.	10	(9.7)				9.9	
Phyone (41a)									
Adult ♂ ♀ pigeons	4	0.3 cc.	7	10.4				11.3	
Antuitrin G[b]									
Hypct. yg. ♂ ♀ pigeons	3	0.5 cc.	7	9.8				9.8	
Anterior pituitary extract (BVP24A of Evans)									
Young ♂ ♀ pigeons	10	4.0 mg.	10	(10.1)				10.1	
Hypct. yg. ♂ ♀ pigeons	8	2.0 mg.	10	(10.1)				10.3	

TABLE 1—*Continued*

Animals		Daily dosage		Mg. calcium per 100 cc. plasma					
Kind and sex	No.	Amount (mg. or units)	Term	Control	After various days of dosage				
					1	2–3	4–6	7–10	11–14
			days						
Corticotrophin + FSH + thyrotrophin (533)									
Young ♀ pigeons	2	2.0 mg.	7	10.3				9.6	
Hypct. ad. ♀ pigeons	2	2.0 mg.	7	9.1				12.2	
Pullets (4 mo.)	3	3.0 mg.	7	12.4				12.9	
Corticotrophin (Nos. 576, 781)									
Young ♂ ♀ doves	4	2.0 mg.	4	(9.5)			9.8		
Young ♂ ♀ pigeons	4	6.0 mg.	6	(9.3)			10.1		
Hypct. yg. ♂ ♀ pigeons	4	6.0 mg.	6	(9.2)			8.2		
Intermedin (Höchst; IG352)									
Young ♂ ♀ pigeons	8	1,000 U.	10	(10.4)				10.6	
Hypct. ad. ♂ ♀ pigeons	2	500 U.	7	9.5				10.1	
Adult ♂ pigeons	2	500 U.	7	(9.5)				10.3	
Prolactin (Nos. 261, 380H, 595H2, 626, 786)									
Hypct. ad. ♀ pigeons	2	8.0 mg.	10	10.0			10.2	11.5	
Young ♂ ♀ pigeons	4	10.0 mg.	6	(9.6)		10.0	9.9		
Thydct. ad. ♂ pigeons	4	20 I.U.	8	9.8				9.8	
Laying hens	2	9.0 mg.	10	27.6			12.4	10.9	
Laying hens	3	10.0 mg.	5	16.4			13.0		
Thymus extract (Hansen)									
Young ♀ doves	3	1.0 cc.[c]	29	(9.5)					9.5
Pineal extract (Hansen)									
Young ♀ doves	2	0.5 cc.[c]	29	(9.5)					9.7
Lactoflavin									
Hypct. yg. ♂ ♀ pigeons	9	13 U.	10	(9.6)				9.5	
P-aminobenzoic acid									
Adult ♂ doves	3	58 mg.	10	9.8				10.2	
Calcium lactate fed									
Young ♂ ♀ pigeons	13	300 mg.	5 hr.	9.4	9.6				
Young ♂ ♀ pigeons	3	300 mg.	10 hr.	(9.4)	8.9				

[a] During first seven days dosage was 3 mg. daily.
[b] This particular sample ("growth" hormone) showed little or no gonadotrophin (FSH).
[c] Three times per week.

Four groups of pigeons were injected over a period of ten days with fairly large doses of "whole anterior pituitary extract," and all groups then had average calcium values slightly in excess of their control; of three such groups injected for four days (not tabulated) one group only showed a slight excess of calcium. The slight excess observed after long-term dosage is probably significant; and, since females were present in all the treated groups, this slight effect may be due to the presence of gonadotrophin in these extracts. If, however, pituitary factors lacking in the above-described "gonadotrophin + throtrophin" preparations are also capable of increasing the plasma calcium they should have given very clear expression to that ability in these tests with the unfractionated extract—including the three (untabulated) tests injected over a period of four days. They did not do so.

Three preparations (Phyone, Antuitrin G, and BVP24A), made by others with a view to concentrating an alleged "growth" factor, are of like interest. Among these it was only the preparation which had the highest content of gonadotrophin, and was also tested on a group which contained two adult females, that gave a probably significant increase of plasma calcium. It is thus indicated that so-called "growth" hormone failed to *depress* the plasma calcium of pigeons of the types studied, and it slightly *increased* the plasma calcium only when the preparation having the highest content of gonadotrophin was tested in the type of pigeon most sensitive to gonadotrophin.

Corticotrophin, acceptably free from other pituitary hormones ("growth," not assayed), was tested in only three groups of young pigeons. When injected over four to six days in such birds it gave no clear evidence of effect on the plasma calcium. Smaller quantities (2 and 3 mg.) of another preparation (No. 533) which contained exceptionally high concentration of corticotrophin, gonadotrophin and thyrotrophin (see Riddle, 39) very definitely increased the plasma calcium of two hypophysectomized adult female pigeons, but did not significantly affect that of two young female pigeons and three young female fowl.

Prolactin, practically free from other pituitary hormones (not tested for "growth"), had no significant effect on the plasma calcium of the several types of pigeons tested. In five laying hens prolactin quickly stopped egg-laying and reduced the high calcium values characteristic of the laying condition to the lower values of the non-laying hen.

Intermedin contaminates most preparations of pituitary hormones and it is often present in large quantity. It is therefore important that intermedin should be tested for its ability to do the things which one or another pituitary derivative is alleged to do. Daily dosage for seven to ten days with 500–1,000 Phoxinus units (0.5 to 1.0 cc.) of intermedin did not significantly affect the plasma calcium of young or adult pigeons of either sex. Hansen's extracts of thymus and pineal glands, in the dosage used, left the plasma calcium of young female doves unchanged at the end of twenty-nine days of treatment.

The possible influence of temporary changes in intake of certain dietary factors was tested. Pipetting 300 mg. of calcium lactate into the crops of young pigeons had no measurable effect on the amount of their plasma calcim five or ten hours later. The daily administration of neither lactoflavin (to pigeons) nor p-aminobenzoic acid (to doves) caused any change in the level of plasma calcium at the end of ten days.

In view of the peculiarly undeveloped state of the ovaries of young birds, and the long term of dosage with gonadotrophin required to cause such ovaries to produce estrogen (and enlarge their oviducts), the data described above indicate that gonadotrophin is the pituitary factor that increases plasma calcium in birds and that it acts through and upon the ovary. The data of table 2, to be examined immediately, provide specific evidence that the production of estrogen in the ovary is the immediate cause of the rise in blood calcium. It is not yet definitely known, however, which form of gonadotrophin (FSH or LH) actually controls the production of estrogen in birds.

THE STEROID HORMONES WHICH INCREASE PLASMA CALCIUM IN BIRDS

The data given in table 2 show that estrogens (estrone, diethylstilbestrol, estradiol, and its benzoate) promptly and very markedly increase the plasma calcium in young and old doves and pigeons of *both* sexes. Neither hypophysectomy, thyroidectomy, adrenalectomy, nor castration prevented or obviously modified this response in male pigeons. In young (four months) male fowl the response to dosage for three days seems definitely less than in females of the same age.

TABLE 2

PLASMA CALCIUM IN PIGEONS, DOVES AND FOWL AFTER DAILY INJECTIONS WITH STEROID HORMONES

Animals		Daily dosage		Mg. calcium per 100 cc. plasma					
Kind and sex	No.	Amount (mg. or units)	Term	Control	After various days of dosage				
					1	2–3	4–6	7–10	11–16
			days						
Dihydrotachysterol (AT10)									
Hypct. adol. ♂ ♀ pigeons	4	0.5–1.0 mg.[a]	16	(9.0)				10.6	9.3
Young ♀ pigeons	5	0.5 mg.	5	9.7			11.1		
Young ♂ ♀ pigeons	4	0.1 mg.	6	9.0	10.2	10.6	8.9[b]		
Young ♂ pigeons	3	0.5 mg.	4	10.6	12.0	11.4	12.3		
Diethylstilbestrol									
Adult ♂ doves	4	0.5 mg.	10	(9.8)				44.0	
Young ♂ ♀ pigeons	4	0.4 mg.	7	(9.3)				20.3	
Young ♂ ♀ pigeons	4	4.0 mg.	4	9.7		23.7	38.2		
Cortin (Klein; Kendall)									
Young ♂ ♀ doves	3	0.3 cc.	10	9.3		9.4		9.1	
Adult ♂ pigeons	3	0.3 cc.	10	9.3				9.3	
Hypct. ad. ♂ pigeons	5	0.3 cc.	10	8.8				9.1	
Adult ♂ pigeons	4	0.3 cc.	9	9.3				9.1	
Thydct. ♂ pigeons	4	0.7 cc.	11	9.6			9.5		9.7
Desoxycorticosterone acetate									
Adrct. yg. ♂ pigeons	2	3.0 mg. + P	3	(9.6)		10.3			
Young ♀ doves	2	1.5 mg.	7	9.5				9.5	
Estradiol benzoate									
Adult ♀ doves	5	1.0 mg.[c]	4	(11.2)			52.0+		
Adult ♀ doves	3	0.1 mg.	7	11.2				18.0	
Young ♂ ♀ pigeons	6	0.5 mg.	5	10.5			31.2		
Hypct. yg. ♂ pigeons	2	0.5 mg.	10	9.1		30.5		47.3	
Thydct. yg. ♂ pigeons	2	0.5 mg.	10	9.4		29.0		47.8	
Hypct. ad. ♂ pigeons	5	200 R.U.	8	9.0				14.4	
Thydct. ♂ pigeons	4	200 R.U.	7	9.8				14.4	
Young ♂ ♀ pigeons	6	200 R.U.	6	10.0			14.0		
Estradiol									
Young ♀ doves	3	0.5 mg.	7	(9.5)				22.6	
Adult ♂ pigeons	3	0.2 mg.	6	9.4			10.6		
Pullets (4 mo.)	3	1.0 mg.	3	12.2		22.1			
Cockerels (4 mo.)	3	1.0 mg.	3	11.8		12.4			
Estriol (in oil)									
Castrate ♂ pigeons	2	100 R.U.	7	9.6				11.6	

TABLE 2—*Continued*

Animals		Daily dosage		Mg. calcium per 100 cc. plasma					
Kind and sex	No.	Amount (mg. or units)	Term	Control	After various days of dosage				
					1	2–3	4–6	7–10	11–16
			days						
Estrone									
Young ♂ ♀ pigeons	3	2.0 mg. + P	11	9.7					43.3
Adult ♂ ♀ pigeons	4	2.0 mg.	10	12.4				46.3	
Young ♂ ♀ pigeons	6	1.0 mg. + P	15	(9.7)			32.3		26.5
Castrate ♂ pigeons	2	1.0 mg. + P	4	9.0			31.4		
Young ♂ ♀ pigeons	4	1.0 mg. + P	29	9.3		36.4		38.8	29.0[d]
Adrct. yg. ♂ pigeons	1	0.6 mg. + P	5	(9.6)			26.5		
Young ♀ doves	2	0.5 mg.	7	(9.5)				21.4	
Young ♂ ♀ pigeons	6	0.25 mg.	6	10.1			19.3		
Young ♂ ♀ doves	6	0.1 mg.	7	(9.8)				12.1	
Hypct. ad. ♂ pigeons	2	0.2 mg.	7	9.3				23.2	
Hypct. cast. ♂ pigeons	2	0.2 mg.	7	9.0				25.1	
Young ♀ doves	2	0.04 mg.	5	10.5			12.7		
Laying hens	2	0.2 mg.	7	21.9				29.5	
Progesterone									
Young ♀ doves	5	1.5 mg.	7	(9.5)				10.5	
Adult ♂ pigeons	2	1.0 mg.	3	(10.6)		12.0			
Young ♀ doves	2	0.5 mg.	5	(10.0)			10.9		
Adult ♂ pigeons	2	1.0 mg.	6	9.5			10.5		
Young ♀ doves	3	0.1 mg.	7	(10.0)				10.9	
Androstendiol									
Adult ♂ pigeons	2	5.2 mg.	7	9.3				9.3	
Adolesc. ♂ ♀ pigeons	3	3.5 C.U.	7	9.8				9.8	
Hypct. ♂ pigeons	2	3.5 C.U.	7	9.3				9.3	
Adult ♀ doves	2	0.5 mg.	7	11.2				9.5	
Androstenedione									
Young ♂ ♀ pigeons	4	3.0 mg.	15	10.8		10.5	10.4		10.2
Androsterone									
Young ♀ doves	3	1.5 mg.	7	(9.5)				9.5	
Testosterone									
Adult ♂ pigeons	4	2.5 mg.	7	9.3					9.2
Young ♀ doves	3	1.5 mg.	7	(9.5)					9.3
Young ♂ ♀ fowl	6	5.0 mg.	3	12.1		12.4			
Non-laying hens	3	5.0 mg.	3	12.2		12.3			

[a] Dosage during first 9 days was 0.5 mg. daily.
[b] This value was obtained at 5 days; at 6 days value was 9.6.
[c] Three injections within a period of 4.5 days.
[d] Later Ca values (3 birds) were: 30.6 (17 days); 33.7 (21 days); 31.4 (24 days); 34.1 at 29 days.

Estriol may or may not be less effective than the estrogens listed above. Higher and more prolonged dosage increases the calcium in greater degree. Cortin did not affect the level of plasma calcium in doves or pigeons. Progesterone was administered to five small groups of doves and pigeons, and a slight apparent increase in calcium was obtained in all cases. This result is therefore probably significant and large doses of this steroid have been shown elsewhere (Riddle and Lahr, 44) to have a weak estrogenic action on the oviducts of immature doves.

Several tests made with relatively large doses of androgens (androsterone, androstendiol, androstenedione, testosterone) were completely negative. Administered over a period of three to seven days these androgens neither increased nor diminished the plasma calcium of doves, pigeons, and non-laying hens.

Dihydrotachysterol (AT10) is related chemically to the steroid hormones and to vitamin D, and both AT10 and vitamin D are used clinically to increase the blood calcium in the absence or deficiency of the hormone of the parathyroid glands. The data given in table 2 show that AT10 increases the total plasma calcium in pigeons, as it does in rats (table 3) and in man. Per unit of weight AT10 is found less effective than is estrogen in increasing the total plasma calcium of pigeons, and McChesney (45) found AT10 "surprisingly ineffective in chicks"; the reverse is true in mammals. Riddle and McDonald (46) found that AT10 increases "diffusible" calcium in pigeons as it does in mammals; others have shown that it is chiefly "bound" calcium that is increased in the plasma of birds by estrogens. Riddle, Rauch, and Smith (45) find that the amount of "bound" calcium is increased by estrogens to an equally great extent in parathyroidectomized and intact pigeons.

THE PITUITARY HORMONES WHICH INCREASE PLASMA CALCIUM IN RATS AND RABBITS

This topic was studied less extensively in rats (table 3) and rabbits (table 4) than in birds, and consistent or clearly significant differences between the action of different pituitary hormones were not observed in those mammals. Most rabbits were injected once only and blood samples were taken twenty-four and (or) forty-eight hours later. Since these tests, particularly with the gonadotrophic preparations, suggested a decrease rather than an increase of serum calcium, most of the tests with rats were made after four to 11 days of treatment. This prolonged treatment of rats was probably unwarranted, and it may be responsible for the lack of consistent results. The four larger groups of rats which were tested with the better gonadotrophic preparations (FSH + thyrotrophin; mare serum powder) all showed slightly higher calcium values after treatment for two hours and for four, seven, and ten days. But, in smaller groups, an apparent decrease was obtained at ten days with Prolan; and a "growth" preparation (Antuitrin G) which was practically free from gonadotrophin seemed more effective than another preparation (BVP24A) which contained much more of it. Results from groups of rabbits tested at one, two, three, ten, and fourteen days of treatment with preparations rich in gonadotrophin suggest an increase in two tests and a decrease in five tests. On the other hand, groups of rabbits injected with prolactin more often showed increases (four groups) than decreases (two groups) of plasma calcium. The results of tests made in rats and rabbits with corticotrophin and intermedin suggest that these hormones also do not affect blood calcium significantly. Great variability of control values for plasma calcium in rabbits has been observed in several laboratories, but not in others. In our colony this variability was a disturbing factor.

THE ACTION OF STEROID HORMONES IN RATS, RABBITS, AND DOGS

It is well established that dihydrotachysterol (AT10) increases the plasma calcium of rats. Results obtained by us with this substance may be noted prior to a consideration of the questionable or less definite effects obtained with steroid hormones. A higher plasma calcium was obtained in five of the six groups treated (table 3) with AT10, and the exception relates to the group given the lowest dosage (five border-line toxic units in the mouse). The results of these tests permit the conclusion that when the normal amount of calcium in the blood of rats was increased by as much as 10 to 25 per cent each of our measurements of a group was sufficiently accurate to show the direction and approximate amount of the change.

At the time our preliminary report (1) was written most of the small groups of estrogen-treated rats had indicated a slight increase in plasma calcium as a result of this treatment; subsequent tests gave little or no evidence of any effect. The data published in our prelimi-

nary report (1) are not reproduced here, and our total evidence provides perhaps some slight evidence that estrogens (and progesterone) tend to increase the plasma calcium of rats—except in parathyroidectomized rats. In the latter type of rat (table 3) our data show that daily doses of 0.1 and 0.3 mg. of estrone did not increase the plasma calcium at two, five, and ten days, though AT10 was fully effective in such rats when treated over five days. It is further notable that treatment of normal and castrate rats with testosterone gave no evidence whatsoever of an effect on plasma calcium.

A group of castrate rabbits injected daily for

TABLE 3

PLASMA CALCIUM IN RATS AFTER DAILY INJECTIONS OF PITUITARY AND STEROID HORMONES

Preparation used	Rats		Daily dosage		Mg. calcium per 100 cc. plasma					
	Kind and sex	No.	Amount (mg. or units)	No.	Control	After various days of dosage				
						1	2–4	5–7	8–10	11+
				days						
Control	Normal ♂ ♀	25			10.9					
Control	Castrate ♂ ♀	12			10.7					
FSH + thyrotr. (517)	Normal ♂ ♀	3	8 mg.	7	10.7			11.3		
Mare serum powder	Normal ♂ ♀	4+3	30 mg.	4; 10	(11.6)		12.5		11.7	
Mare serum powder	Normal ♂ ♀	8	30 mg.	0[a]	(11.0)	11.7[a]				
Prolan (Elb.)	Normal ♂ ♀	2	30 R.U.	10	(10.6)				9.9	
A.P. extr. (BVP24A)	Normal ♂	2	2 mg.	11	11.2					10.7
Antuitrin G (No FSH)	Normal ♀	2	0.2 cc.	11	(11.5)					12.3
Corticotrophin (664)	Spayed ♀	2	5 mg.	11	11.1					10.8
Prolactin (469H)	Normal ♂	8	5–24 I.U.	31	(10.9)					10.7
Prolactin (469H)	Normal ♂ ♀	4+4	5–8 mg.	4; 10	(10.8)		9.7		10.7	
Intermedin	Normal ♂	2	100 U.	7	(11.2)			11.5		
Dihydrotachysterol (AT10)	Normal ♂ ♀	9	24 U.	5	10.2			12.8		10.9[b]
Dihydrotachysterol (AT10)	Normal ♂	5	24 U.	5	10.9			12.2		
Dihydrotachysterol (AT10)	Normal ♀	4	5 U.	5	(11.3)			11.0		
Dihydrotachysterol (AT10)	Normal ♀	4	10 U.	5	(11.3)			12.3		
Dihydrotachysterol (AT10)	Normal ♀	4	20 U.	5	11.3			13.2		
Dihydrotachysterol (AT10)	Parathydct. ♂ ♀	9	24 U.	5	7.4			12.8		10.2[b]
Cortin	Hypct. ♂ ♀	4	0.2 cc.	10	(9.7)					10.2
Progesterone	Normal ♂	4	0.2 mg.	10	(10.4)				11.7	
Progestin	Normal ♂ ♀	3	0.2 Rb.u.	10	(11.1)				11.6	
Diethylstilboestrol	Normal ♂	5	2.0 mg.	1	(10.4)	10.6				
Diethylstilboestrol	Normal ♂ ♀	2	2.0 mg.	2	(10.6)		10.5			
Diethylstilboestrol	Spayed ♀	3	2.0 mg.	1	(9.4)	9.8				
Estrone	Normal ♂	6	3.0 mg.	5	10.8			10.3		
Estrone	Normal ♂ ♀	3+6	0.5 mg.	3; 5	(10.3)		10.6	10.0		
Estrone	Normal ♀	3	0.25 mg.	3	(11.1)		10.0			
Estrone	Normal ♂	5	0.3 mg.	8	10.8[c]		11.2		11.2[c]	
Estrone	Parathydct. ♂ ♀	10	0.3 mg.	10	7.6		7.1		7.1[d]	
Estrone	Parathydct. ♂ ♀	5	0.1 mg.	7	7.2			7.3		
Testosterone	Normal ♀	2	0.5 mg.	11	10.9				10.9	
Testosterone	Castrate ♂	3	0.5 mg.	10	10.7				11.1	
Testosterone	Normal ♂	5	0.5 mg.	3	(10.8)		11.0			
Testosterone	Normal ♀	5	6.0 mg.	5	11.1			10.7		

[a] Samples taken only 2 hours after injection.
[b] These values, probably representing a prolonged effect, were obtained at 13 (or 14) days after last injection.
[c] Thirteen days after last injection another (control) value of 10.2 was obtained.
[d] Fourteen days after last injection a (control) value of 7.2 obtained.

TABLE 4

PLASMA CALCIUM IN NON-FASTING RABBITS AFTER INJECTION WITH PITUITARY OR STEROID HORMONES
Most single injections were made into an ear vein; others subcutaneously

Preparation used	Rabbits		Daily dosage		Mg. calcium per 100 cc. plasma				
	Kind and sex	No.	Amount (mg. or units)	Term	Control	At various days of dosage			
						1	2–3	4–6	7–10
				days					
Prolactin (380H)	Normal ♂ ♀	4	250[a] I.U.	6	13.3[a]	13.5	14.6	14.4	
Prolactin (380H)	Normal ♀	5	180 I.U.	1	15.8	14.9			
Prolactin (380H)	Castrate ♀	2	280 I.U.	1	14.2		16.1		
Prolactin (380)	Normal ♂ ♀	3	55 I.U.	1¼	15.3	15.0			
Corticotrophin	Normal ♂ ♀	3	25 mg.	5	13.9			15.4[b]	
Control only	Normal ♂ ♀	24	0	0	13.7				
Thyrotrophin+FSH	Normal ♂ ♀	6	20–80 G.P.U.	1	15.4	13.6			
FSH+Thyr. (643)	Normal ♀	4	10 mg.	14	13.5		13.4		14.3[c]
LH of Fevold	Normal ♂ ♀	3	3 mg.	1	12.6	10.3	13.4		
Placental extr.	Normal ♀	2	30 mg.	1	16.1	15.3			
Mare serum	Normal ♀	1	0.1 cc.	1	15.9	14.6			
Prolan (315E)	Normal ♀	4	3–5 R.U.	1	14.4	14.6			
Intermedin	Normal ♂ ♀	3	1,500 U.	3	14.4	13.5			
Estradiol benzoate	Normal ♂ ♀	2	1,000 R.U.	4	14.3			15.0	
Estrone	Normal ♀	3	3,000 R.U.	8	12.6		12.9		13.1
Dihydroestrone	Castrate	2	400 R.U.	14[d]	14.3				15.4[d]
Dihydroestrone	Castrate	4	3,000 R.U.	5	13.8			13.5	
Estrone	Castrate	1	20,000 R.U.	7	13.1				15.2
Estrone	Castrate	3	Pellets[e]	10	13.5		14.6		14.5[e]
Testosterone	Castrate	3	5.0 mg.	8	13.1		13.1		13.1

[a] Only 100 units daily after first injection. Control, fasted; food offered later.
[b] Sample taken 3 days after last injection.
[c] Both at 14 days of dosage, and 14 days thereafter, values of 14.1 were obtained.
[d] Subcutaneous and intraperitoneal injections on alternate days. At 14 days 14.8 mg. Ca was obtained.
[e] Three pellets (wt. nearly 47 mg.) implanted in each rabbit; 4.4, 4.7 and 10.4 mg. absorbed by the 3 rabbits. At 13 days after removing pellets 13.9 mg. Ca was obtained.

eight days with 5.0 mg. of testosterone showed no change in plasma calcium after three and eight days of treatment. Our earlier tests on the action of estrogens on the plasma calcium of normal rabbits usually employed less than 400 R.U. daily and the results (not tabulated here) seemed entirely negative (1) in view of the wide fluctuations observed in untreated controls. A second series of tests, made chiefly on non-fasted castrates, utilized much heavier or more prolonged dosage (table 4). The results obtained clearly suggest that huge doses of estrogen tended to increase the plasma calcium of this series of rabbits. Though these increases were small they were obtained in eight of the nine tests made on six groups of rabbits, and the largest apparent increase was obtained after the heaviest dosage; again, the changes in plasma calcium observed after injections with various pituitary hormones were far less regular and consistent than those obtained after heavy doses of estrogens. Clearly, however, the results of the two series of tests on rabbits are unsatisfactory.

In a third series of tests completed recently it was possible to make a more comprehensive study of the effect of daily injections (and of pellets) of estrone and estradiol benzoate on the plasma calcium, inorganic phosphorus and protein nitrogen of rabbits which were bled (about 4 cc. per bleeding) five times over a period of seven days. Since an effect on the blood calcium, if present, may be limited in duration and in the time of its appearance tests of the kind shown in table 5 are useful. There is danger, however, that the repeated bleedings may lead to dilution

of the blood. Constancy or change of the protein nitrogen should provide information concerning the extent of this hemodilution. The data obtained indicate notable hemodilution only in groups treated with 3 mg. of estrone and with 50 mg. of whole anterior pituitary extract; these two groups were treated and measured simultaneously. In both cases, however, the drop in calcium was often greater than can be accounted for by hemodilution as this was measured by decrease of protein nitrogen; in both of these cases the inorganic phosphorus was also decreased by the treatment. It is notable that whole anterior pituitary extracts would be expected to *increase* the plasma calcium, and that actually the preparations used (it was dry, not fresh) led to a greater decrease than did estrone. Bleeding alone was probably not responsible for the two observed cases of hemodilution, since similar evidence for dilution of the blood was not obtained with "control" substances. It is probable that voluntary fasting promoted hemodilution in the two cases where this was most marked.

Enforced fasting, when practised in these tests, was always started twenty-four hours before the control blood sample was drawn and injections started. This fast was continued until after the first test (four-hour) sample was drawn. Owing to a modification in the technique of these particular calcium determinations (colorimetric) the values shown in table 5 are slightly higher than those of table 4. Though the plasma calcium tended to decrease also under treatment with two of the "control" injections (sesame oil, muscle extract) it was fully maintained under injections of propylene glycol. It is therefore evident that, under the conditions imposed in

TABLE 5

A THIRD SERIES OF TESTS ON RABBITS TO OBSERVE THE COMBINED EFFECT OF DAILY INJECTIONS OF ESTROGENS (AND WHOLE ANTERIOR PITUITARY EXTRACT) AND FREQUENT BLEEDINGS ON LEVELS OF PLASMA CALCIUM, INORGANIC PHOSPHORUS AND PROTEIN NITROGEN. TWO GROUPS (UPPER OR LOWER HALF OF TABLE) TESTED SIMULTANEOUSLY; AND ALL GROUPS RETESTED AFTER AN INTERVAL OF 20 TO 21 DAYS

First and later tests on same group	Substance (of plasma) measured	Number of rabbits	Values in mg. per cent				
			Control	After injection (or implantation)			
				4 hours	24 hours	3 days	7 days
Estrone, 3 mg., in sesame oil (initial fast, 28 hours)[b]							
First	Calcium	4[c]	17.6	17.8	16.0	15.7	15.8
	Inorganic P		7.79	7.26	6.14	5.92	5.66
	Protein N		12.0[a]	11.3	10.5	11.5	11.4
Sesame oil only (fasted total of 72 hours). Control							
After 21-day interval	Calcium	4[c]	15.7	16.0	15.4	15.2	14.3
	Inorganic P		4.55	5.05	4.63	3.97	5.03
	Protein N		10.7[a]	10.9	11.1	11.3	11.5
Dried extract whole ant. pituitary, 50 mg. (28 hr. fast)[b]							
First	Calcium	4	17.6	15.8	16.1	14.4	14.7
	Inorganic P		9.06	7.11	7.29	7.02	7.25
	Protein N		11.6[a]	11.1	10.2	10.3	10.4
Injected daily with 50 mg. dried extract of muscle (fasted total of 72 hours). Control							
After 21-day interval	Calcium	4	16.3	15.7	15.2	14.0	14.0
	Inorganic P		4.97	5.67	5.61	5.46	6.31
	Protein N		11.7[a]	11.7	11.6	12.0	12.1

TABLE 5—*Continued*

First and later tests on same group	Substance (of plasma) measured	Number of rabbits	Values in mg. per cent				
			Control	After injection (or implantation)			
				4 hours	24 hours	3 days	7 days
Estradiol benzoate, 1.5 mg. in propylene glycol (initial fast, 28 hours)							
First	Calcium	4	15.4	14.5	14.1	15.1	15.1
	Inorganic P		6.72	7.47	6.80	7.35	6.71
	Protein N		9.0[a]	8.3	8.5	9.2	9.4
Implanted, 2 pellets (10 mg. each) estradiol benz. Not fasted							
After 20-day interval	Calcium	4	16.2	15.6	15.8	15.1	15.8
	Inorganic P		6.00	6.29	6.15	7.17	6.03
	Protein N		9.6[a]	9.1	9.2	9.5	9.5
Propylene glycol only (initial fast, 28 hours). Control							
First	Calcium	3	15.1	14.9	14.5	15.2	15.6
	Inorganic P		7.08	6.80	6.89	6.70	6.77
	Protein N		9.8[a]	8.8	8.8	9.3	10.0
Implanted, 2 pellets (10 mg. each) estradiol benz. Not fasted							
After 20-day interval	Calcium	3	16.4	15.9	15.3	14.8	15.4
	Inorganic P		6.68	6.48	6.60	6.87	5.83
	Protein N		10.4[a]	9.5	9.8	9.9	10.0

[a] Mg. per cc. plasma.

[b] During following 2 or 3 days these two groups of rabbits ate less than usual (estrone) or almost nothing (anterior pituitary). When retested these groups were therefore fasted for 72 hours.

[c] One of this group was a castrate injected twice daily with 10 mg. of estrone; its response did not differ from others of the group.

these tests, estrone and estradiol benzoate did not increase the plasma calcium of normal rabbits. The three groups treated with estradiol benzoate showed no significant change in the inorganic phosphorus of the blood.

Results of tests of the action of estrone and estradiol benzoate on the blood calcium of dogs are given in table 6. The number of tests is fewer than is desirable, but the results consistently indicate an increase in the plasma calcium of these dogs. On the basis of these tests and of tests made by others it seems probable that dosage over a period of only one or two days, with approximately 3 to 5 mg. (3,000–5,000 R.U.) daily, produces a larger increase in the blood calcium of dogs than does smaller or more prolonged dosage.

DISCUSSION

Consistent but inadequate evidence for ability of estrogens temporarily to increase the plasma calcium was obtained in dogs. Only one of three segments of our numerous data on rabbits gave a like result; data obtained from rats were suggestive but not conclusive. From the beginning of this study it was quite clear that mammals offer much greater resistance to increase of their plasma calcium by estrogen than do birds. The present study appears to provide some evidence that certain mammals (e. g., rats) offer greater resistance than others (e. g., dogs) to this action of estrogen; but other considerations should not be overlooked. Because of their small size, and the associated difficulty of obtaining several samples from the same rat, it

TABLE 6

PLASMA CALCIUM IN DOGS AFTER DAILY INJECTIONS (MOSTLY SUBCUTANEOUS) OF ESTROGENS

Animals		Preparation used	Daily dosage		Calcium found	
No. and sex	Weight		Amount	Term	Control	Test
	kg.		*r.u.*	*days*	*mg.*	*mg.*
♀ A	7.0	Progynon B	3,000	2	9.8	13.0
		Progynon B	3,000	9		11.4
♀ B	5.5	Progynon B	3,000	2	(10.9)	11.6
		Progynon B	3,000	9		11.1
♀ C	6.9	Estrone	3,000[a]	1	10.4	14.5
		Estrone	1,000[b]	8		12.3
♂ D	9.0	Estrone	200[c]	5	11.3	12.1
♀ E	11.9	Estrone	400[c]	5	10.5	11.7

[a] One injection only.
[b] After injection of 3,000 R.U. on first day, 1,000 R.U. was given daily for 7 days.
[c] Intramuscular injections.

is more difficult to determine either the optimum dosage or the time of maximum effect in rats than in rabbits and dogs. Again, the maximum increase in the rat may be limited to 105 per cent of the control value (100 per cent), and this difference will not always be detected by present methods of measuring plasma calcium. In principle it is unimportant whether the plasma calcium responds to estrogen by a rise of 5 per cent or of 100 per cent, and likewise unimportant whether the rise persists or soon disappears. A small and temporary increase in the plasma calcium of the dog, if it follows the ingress of hitherto absent (or a minimal supply of) estrogen in the blood, serves to place the observed closure of the epiphyses in estrogen-treated dogs (7) into a general picture with the increased plasma calcium values in pigeons at the precise time that they form new medullary bone (4). Finally, it should not be overlooked that estrogens cause medullary bone formation in many (or all) mammals, and that this certainly provides a special exit for calcium of the blood during the term that estrogen is usually administered. Thus, in mammals given estrogen, the rate of mobilization and transport of calcium is probably somewhat increased even in those cases where our measurements show that no change in the momentary value of the plasma calcium has occurred. It was this special and doubly-expressed action of estrogens—on the blood and on the skeleton—that became of chief interest when we obtained evidence that estrogens do and androgens do not increase the plasma calcium in both birds and mammals.

Recent investigations on the effect of estrogens on the blood calcium are not in good agreement. Marlow and Koch (48) reported no significant effect in either fowl, rats, or rabbits. Very large increases have been reported recently by others in fowl (8, 12, 49, 50), in pigeons (10, 47, 51), in ducks (52) and in English sparrows (11). In many of these studies skeletal changes were also observed, and in one case (51) data confirming the lack of effect of testosterone on the blood calcium of pigeons were obtained. Bach (53) reported rather surprising increases in the plasma calcium, and a decrease in the calcium of muscle, bone, and skin, in a few rats treated daily with 30 to 100 gamma of estrone; in addition Bach stated that the amount of ingested calcium which was retained by these rats was increased during the first few days and then decreased. Levin and Smith (54) used smaller and more prolonged dosage than was used in the present tests and reported failure to obtain significant effects in rats, rabbits, and monkeys. Zondek and Marx (49) gave no data but stated that they had observed no increase in the blood calcium of rats, rabbits, and men treated with estrogens. Day and Follis (55) reported a significant increase in the serum calcium of groups of rats (except senile rats) treated with estradiol benzoate. They point out that in all instances the groups (rats, rabbits) studied by Levin and Smith showed slightly higher calcium values than did their controls. In rachitic dogs whose calcium could be raised only slightly with parathormone the injection for four days of either gonadotrophin or 1,000 R.U. of estrone decreased the plasma calcium (56). From three dogs dosed with estradiol benzoate and three others given testosterone—all in huge doses—Cheymol and Quinquaud (57) obtained no informative results. Campbell and Turner (37) state that minute doses (0.5 to 20 gamma) of estrone and enormous doses (10 mg.) of diethylstilbestrol injected daily for five days did not significantly affect the blood calcium of a very few small groups of young male guinea pigs. Results tabulated above (table 3) confirm Dixon's (28) conclusion that the blood calcium of parathyroidectomized rats is not increased by estrogen.

The present study supplies a partial solution

of the question of the identity of the pituitary hormone which increases the plasma calcium. The gonadotrophic complex is clearly shown to be responsible for the observed increases of plasma calcium in birds. It is not probable that gonadotrophin acted through or upon the parathyroids in the present tests, since it has now been shown by Riddle and others (47) that estrogens are almost or quite as effective in increasing total blood calcium in completely parathyroidectomized as in intact pigeons. But estrogen does not maintain a normal level of "diffusible" calcium in parathyroidectomized pigeons (46), nor in thyro-parathyroidectomized rats (28; and table 3). Results hitherto obtained do not exclude the possibility that still another pituitary hormone sustains parathyroid activity. It is a fact that parathormone, AT10, and vitamin D increase the diffusible or ionic fraction of the blood calcium in much greater proportion and degree than does estrogen. Again, neither gonadotrophin nor other pituitary hormones or extracts consistently increased the plasma calcium of rats and rabbits. The number of tests made on these animals with whole or unfractionated pituitary extracts is, however, too small to warrant any additional conclusion. Indeed, in some or most species of mammals it may be necessary to use hypophysectomized individuals and pituitary hormones more highly purified than those now obtainable in order to learn which pituitary hormone, if any, is capable of stimulating the parathyroids.

Friedgood and McLean (58) obtained an apparently significant increase (from 11.1 to 12.0 mg. per cent) in the serum calcium of nineteen guinea pigs injected six to nine days with alkaline extract of anterior pituitary. Like most other authors they regarded this increase as evidence that the extract used had parathyrotrophic activity. Campbell and Turner (37) report an apparent slight decrease in the plasma calcium of eight adult rats injected twice daily for six days with moderate doses of whole sheep pituitary. Their concurrent study of this and other dosage on the parathyroids of rats led these authors to conclude that "the existence of a parathyrotrophic (pituitary) factor is extremely doubtful."

Berovitch and associates (59) made intravenous injections of fresh anterior lobe extracts into dogs. The equivalent of 3 gm. of the fresh tissue given to each of four normal dogs increased the blood calcium and phosphorus at two to five hours but not at seven to nine hours. In four thyro-parathyroidectomized dogs whose blood calcium had dropped to 5.7 mg. per cent (P raised to 9.2 mg. per cent) the anterior pituitary extract did not augment the calcium nor decrease the phosphorus during a period of nine hours. The special ability of gonadotrophin to increase the plasma calcium in female birds has been confirmed by Pfeiffer, Kirschbaum, and Gardner (60). These authors injected adult English sparrows over a period of twenty-three days, in the non-breeding season, with 15 R.U. daily of pregnant mare serum (Gonadin); a calcium value of 20.5 mg. per cent was obtained from females and of 9.7 mg. per cent from males. Reviews of the extensive literature on some or all aspects of the present problem have been written by Campbell and Turner (37), Gardner and Pfeiffer (61), McLean (62), Silberberg and Silberberg (63), and by Landauer and Zondek (64).

The special relationship of estrogens to developmental effects in the skeleton has now been observed in several species of birds and mammals. Those studies, though not directly related to the data tabulated in this paper, do provide a direct confirmation of a part of a general theory of the role of estrogen which we formulated earlier (1) on the basis of parts of the present data. That general theory is again stated below.

The disclosure of unlike effects of estrogens and androgens on the lime of the blood of birds and mammals, when joined to other available observations which demonstrate also their unlike effects on bone in both of these groups of vertebrates, is believed to have practical and theoretical importance in medicine, in sex research, and in anthropology. It can hardly be presumed that no special disturbance or pathology in women is associated with a tendency of their special (and cyclically produced) sex hormone to place extra calcium in their blood and selectively to resorb or deposit calcium in their bones. To students of sex difference this particular disparity of action of the two types of sex hormones—despite possible antagonisms or synergisms which may exist among the steroid hormones—certainly assists a comprehension of the skeletal and mineral metabolism differences which were quite inexplicable so long as an "asexual" thyroparathyroid apparatus and vitamin D were considered the prime supervisors of the utilization and deposit of lime. More prolonged epiphyseal

growth of the bones in human castrates, and estrogen-induced epiphyseal closure in dogs and bone resorption in rodents, permit the anatomist and anthropologist to regard the monthly sex cycles of females as means for both temporary interruption of calcium deposit and a more rapid maturation of parts of their skeletons; these effects perhaps provide part of the reason for a lower stature in sister than in brother. Again, in some individuals and races these sex cycles begin earlier than in others, and relatively high estrogen production now known to characterize (temporarily) some individuals may later be found to characterize some races. Despite the known importance of genetic factors, this dissimilar effect of the two types of sex hormones on blood and bone should assist our understanding of the complicated problem of the statural differences of individuals, sexes, and races.

SUMMARY

The pituitary hormone which increases plasma calcium in doves, pigeons, and fowl is gonadotrophin. It is not known whether follicle stimulating or luteinizing gonadotrophin is chiefly concerned.

Gonadotrophin increases the plasma calcium only in birds whose ovaries can be sufficiently matured to produce estrogen during the period of treatment. Gonadotrophin is ineffective in males and in ovariectomized pigeons and fowl. It is effective in hypophysectomized and in thyroidectomized adult female pigeons.

Less extensive study failed to associate any pituitary hormone with ability to increase the plasma calcium in rats and rabbits. Slight evidence was obtained for the effectiveness of very short-term dosage of rats with gonadotrophin; in rabbits this treatment was ineffective.

Estrogenic hormones—estrone, estradiol and its benzoate, estriol, diethylstilbestrol—all have specific ability to increase the plasma calcium (the "bound" fraction) in doves, pigeons and fowls of both sexes and at all ages at which tests were conducted. These estrogens are approximately equally effective in normal, hypophysectomized, castrate, thyroidectomized, and adrenalectomized pigeons.

The effect of estrogen on the plasma calcium of birds is a direct function of the dosage used. Under repeated daily dosage the maximum calcium values are attained only after several days.

Large daily doses of progesterone, probably because of appreciable estrogenic activity of this steroid, cause a slight increase in the plasma calcium of doves and pigeons. Moderate doses of cortin and desoxycorticosterone acetate do not affect the blood calcium of doves and pigeons.

In doses of 1.5 to 5 mg. daily neither of four androgens tested—androsterone, androstendiol, androstenedione, testosterone—showed any ability whatever to increase the plasma calcium of doves, pigeons or fowl.

Estrogens did not clearly affect the level of plasma calcium in normal rats. Confirming Dixon, estrogen does not increase the blood calcium of parathyroidectomized rats. Confirming others dihydrotachysterol increases plasma calcium as effectively in parathyroidectomized rats as in normal rats.

Huge doses of estrogens (3 to 20 mg. daily) usually increased the plasma calcium in several tests made on non-fasted, normal, and castrate rabbits; but neither high nor low dosage maintained a normal plasma calcium in a greater number of tests on intact and castrate rabbits which were frequently bled and in which hemodilution usually occurred. In rabbits of the last-named type the plasma inorganic phosphorus usually remained at a constant level.

Heavy daily doses (3,000 R.U.) of estrogens significantly increased the plasma calcium in inadequate tests made on five dogs.

In doses of 5 or 6 mg. daily over five to eight days testosterone showed no ability whatever to increase the plasma calcium in normal female rats and in castrate rabbits.

This demonstration of a dissimilar action of the two types of sex hormones on the blood calcium is united, as was done in our preliminary report in 1936, with facts which indicate their unlike effects on the development of the skeleton in birds and mammals. The two groups of facts provide the basis for a unified view of certain sex differences encountered in medicine, sex research, and anthropology. That general view or theory is restated and discussed.

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After this manuscript was prepared we learned of a related and important series of studies by Benoit, Fabiani, Grangaud, and Clavert (*Bull. Soc. Chim. Biol.* **23**: 1481–1491, 1941), and by Clavert (Thesis, Univ. of Algiers, 1–184, 1942). These authors reported that in ducks parathyroidectomy prevents the calcemia which estrogens produce in intact ducks. The hypophysis and thyroid were not essential to, but their presence increased the action of estrogen upon, increase of blood calcium and hyperossification of bone in both pigeons and ducks.

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THEORETICAL VELOCITY CURVES OF CLOSE BINARY SYSTEMS

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ABSTRACT

The aim of the present study will be to investigate the theoretical radial velocities of rotating components of close binary systems—in full light as well as during eclipses—taking account of appropriate distortion of the components due to their axial rotation and mutual tidal action. The form of each component is adopted to be one of equilibrium under instantaneous centrifugal and tidal forces; and the surface brightness of the components, apart from ordinary limb-darkening, is supposed to vary proportionally to local gravity.

The effects, upon radial velocity, of axial rotation of distorted configurations will be investigated to the degree of accuracy to which their form can at present be regarded as known—i. e., as far as effects of the second, third, and fourth spherical harmonic deformations are concerned. After a brief general introduction, equations of the problem are set up and the amount of non-orbital radial velocity is evaluated for any moment in full light as well as within eclipses—regardless of whether the star undergoing eclipse is the larger or the smaller of the two and whether the eclipse is partial or annular. The theoretical velocity curves within minima turn out expressible in terms of the same families of functions which were found to constitute the theoretical light curves of close eclipsing systems; and their explicit forms given in this paper should enable one to derive the equatorial velocity of distorted components from the rotational effect observed during eclipses.

Between minima, the axial rotation of tidally distorted components is found to contribute significant amounts to their observed radial velocities. The second harmonic distortion of limb- and gravity-darkened ellipsoids will impress its effects in such a way as to lead the orbit computer to a spuriously eccentric orbit characterized by a longitude of periastron usually (though not necessarily always) equal to 90°. The third-harmonic distortion would contribute to the star's radial velocity even if the latter were uniformly bright, and will generally affect the determination of amplitudes of the radial-velocity curves. The fourth harmonic should combine with the second in its eccentricity-simulating effects.

As a corollary to the foregoing results it was possible to prove that, to every coefficient of limb-darkening of an ellipsoidal configuration, there corresponds a certain small amount of gravity-darkening which will render the isophotae on the apparent disk symmetrical with respect to the projected center of mass of the respective body. This appears, however, to be an exclusive property of the second-harmonic distortion; for with the appearance of the third and higher harmonics the isophotae can no longer form a symmetrical family of curves whatever the limb- or gravity-darkening.

The effects of tidal distortion upon radial velocities, together with similar effects due to reflected light, must naturally superpose upon purely orbital velocities of the revolving components to yield a resultant which is accessible to observations. It is therefore urged that the theoretical contributions of non-orbital origin, arising from both the ellipticity and reflection, be removed from the measured radial velocities of components of close binary systems before a conventional solution for orbital elements is carried out; for only then elements may be obtained that are reasonably free from any obvious source of systematic errors.

I. INTRODUCTION

THE subject of the present study may properly require a few words of introduction. It is a well known fact that the observed periodic variations in radial velocities of spectroscopic binary systems may be regarded as wholly due to orbital motion only provided that their components are so far apart that their relative dimensions can be ignored in comparison with their separation, and the components regarded as mere luminous points. Should, however, the dimensions of the components amount to a sizeable fraction of their separation, their radial velocities would continue to be purely orbital only if either the components possessed no rotational momentum, or (under certain circumstances) the distribution of brightness on their surfaces were uniform or symmetrical with respect to the projected center of mass. So far as the present observational evidence goes, however, the components of close binary systems do seem to rotate—with a speed equal to the Keplerian angular velocity or exceeding it—around an axis that is perpendicular to the orbital plane or approximately so. Moreover, the average separations of components in known spectroscopic binaries make it clear that such components cannot in general be regarded as spheres: centrifugal and tidal forces prevailing in close binary systems must cause their components to deviate from spherical form and, in addition, to have a non-uniform surface brightness. In point of fact, the intensity-distribution on apparent disks of components of close binaries could not remain symmetrical with respect to the projected center of mass, because of reflected light, even if the components were spherical. The reflection, like darkening of distorted stars,

will thus also allow the axial rotation of the components to contribute to their observed radial velocities. All these effects will necessarily render the resultant radial velocities of rotating components of close binary systems to differ from velocities of their centers of mass; terms arising from axial rotation will superpose upon purely orbital velocity to yield a resultant which, if analyzed in a conventional manner, would furnish elements of spectroscopic orbits that are systematically in error. It appears, therefore, presently that no substantial progress in our knowledge of close spectroscopic binaries can be achieved until the effects, upon radial velocity, of axial rotation and orbital motion of their components are satisfactorily disentangled. This sets the task which we are going to confront.

In more specific terms, our aim will be to investigate the form and meaning of the contributions, to observed radial velocities, arising from axial rotation of distorted components of close binary systems to the degree of accuracy to which their form may at present be regarded as known—i. e., as far as effects of the second, third, and fourth spherical harmonic distortion of limb- and gravity-darkened configurations of arbitrary structure are concerned. In doing so we shall not confine our attention to theoretical velocity curves of close binary systems in "full light" alone. We shall equally consider the more general and far more difficult case of our binary being an eclipsing variable and shall investigate, to the same degree of accuracy, the theoretical velocity curves of such systems within eclipses as well. Our present investigation will thus parallel broadly in scope that of light curves of close eclipsing systems published by the writer in these *Proceedings* three years ago;[1] and in spite of an outwardly different nature of both problems, a study of theoretical velocity curves of close binary systems will be found to follow so similar lines that frequent appeal to the earlier memoir—which in what follows will be consistently referred to as paper I—will materially facilitate our present proposition. In particular, we shall find it possible to express the theoretical velocity curves in terms of the same types of functions which constitute the theoretical light curves of close eclipsing systems; and since all such functions have already been exhaustively investigated in paper I our present task will prove simpler than it may have appeared at the first sight.

A study of radial velocities invoked by axial rotation of distorted stars has been paid only a scanty attention by earlier investigators; in fact little or no systematic work on it has been done so far. In a note entitled "A source of spurious eccentricity in spectroscopic binaries" T. E. Sterne[2] has previously called attention to the effects, upon radial velocity, of rotating components of close binary systems, due to their second-harmonic distortion and pointed out that such effects would be ordinarily interpreted as indications of slightly eccentric orbits with the apsidal lines parallel to the line of sight. The effects of reflection upon velocity-curves of spectroscopic binary systems have subsequently been studied by the present writer.[3] He found that the principal effects of reflection are systematically to diminish the amplitudes of orbital velocity-curves and to make their ascending branches steeper than the descending ones. The spurious eccentricity arising from reflection should therefore tend to reinforce that due to limb-darkening, and neutralize that due to gravity-darkening of tidally distorted components. In the present paper we shall extend the scope of Sterne's investigation to effects of the third and fourth tidal harmonic distortion; but shall have nothing to add to the writer's previous work on the reflection effect. Throughout this paper we shall be concerned with effects of the proper light of both components only.

If our binary system happens to be also an eclipsing variable, the object of our study will become vastly more complex because of the fact that, during eclipses, the observed radial velocity of a star is an average taken necessarily over the visible fraction of the apparent disk only. The departures, during eclipses, of the observed radial velocities from simple orbital motion are known as "the rotational effect"[4] and become conspicuous in many eclipsing variables. The first attempt at an analytical interpretation of the rotational effect is due to R. M. Petrie,[5] who considered the stars to appear as uniformly

[1] *Proc. Amer. Philos. Soc.* **85**: 399, 1942.

[2] *Proc. Nat. Acad. Sci.* **27**: 168, 1941.

[3] *Proc. Amer. Philos. Soc.* **86**: 351, 1943.

[4] Observed by Schlesinger, *Publ. Allegheny Obs.* **1**: 134, 1909. Independently predicted by Hellerich, *Astr. Nachr.* **216**: 276, 1922; and actually discovered by Rossiter, *Astrophys. Jour.* **60**, 15, 1924, and McLaughlin, *Astrophys. Jour.* **60**, 22, 1924.

[5] *Publ. Dom. Astr. Obs.* **7**, 133, 1938.

bright circular or elliptical disks. His formulae were later rederived by a more general type of analysis and extended to limb-darkened stars by the writer[6]. In the present paper we shall extend the analysis outlined in this latter note to the general case of limb- and gravity-darkened components of close binary systems taking account of the second, third, and fourth harmonic distortion due to their own rotation and mutual tidal action. As in the theory of light curves of close eclipsing systems, the results will prove to be anything but simple. Their complexity appears, however, to be inherent to the type of analysis employed and cannot be removed as long as we continue describing the form of slightly distorted configurations in terms of spherical harmonics of integral orders.

In the last part of the present paper we shall briefly point out the way in which the rotational contributions to observed radial velocities out of eclipses, if not allowed for, should vitiate certain elements of spectroscopic orbits of close binary systems. In particular, the circumstances will be investigated under which the effects of fourth-harmonic tidal distortion should tend to reinforce or cancel the eccentricity-simulating effects of the second harmonic, as well as the way in which the third-harmonic distortion will affect the amplitudes of orbital radial-velocity curves.

II. EQUATIONS OF THE PROBLEM

Let us consider a binary whose components revolve in space around their common center of gravity and rotate like rigid bodies—an assumption justified on grounds of simplicity—about axes that are perpendicular to the orbital plane. Let, furthermore, the radial velocity of the component at any moment be $V + \delta V$, where V stands for velocity due to the orbital motion and δV for contribution arising from axial rotation of the respective star. The amount of this contribution is obtained, by definition, if we multiply the radial velocity at any point of the rotating star by the corresponding element of light, integrate over the whole apparent disk (or a visible portion thereof), and divide by the proper light of the respective star.

In order to study the non-orbital contribution δV to the observed radial velocity, we find it convenient to identify the origin of coordinates with the center of mass of the star under consideration—which will hereafter be consistently referred to as the primary component—and adopt an orthogonal frame of reference XYZ whose X-axis is constantly coincident with the line joining the centers of the two components, and Y with that of rotation of the primary star. Let, furthermore, r, θ, ϕ denote the spherical polar coordinates in the XYZ-system. The light element dl is then evidently equal to

$$dl = r^2 J \cos\gamma \sin\theta d\theta d\phi, \tag{1}$$

where $r(\theta, \phi)$ specifies the boundary of the distorted star; γ, the angle of foreshortening; while J, the surface brightness at any particular point of the primary's apparent disk, is clearly given by[7]

$$J = H(1 - u + u\cos\gamma), \tag{2}$$

$$H = H\left(1 - \tau\left[1 - \frac{g}{g_0}\right]\right), \tag{3}$$

where g and g_0 stand for the local and mean gravity over the distorted surface; u and τ for the coefficients of limb- and gravity-darkening;[8] while H_0 is the mean intensity of radiation emerging normally to the surface of the star and is supposed to be constant.

On the other hand,

$$\cos\gamma = ll_0 + mm_0 + nn_0, \tag{4}$$

where l, m, n, and l_0, m_0, n_0 stand for the direction cosines of a surface normal and line of sight, respectively. If ϕ denotes the true anomaly (phase angle) of the secondary component in its relative orbit, reckoned from the inferior conjunction (the moment of mid-primary minimum in case of eclipsing stars), and i the inclination of the orbital plane to the celestial sphere, then

$$\begin{aligned} l_0 &= \cos\psi \sin i, \\ m_0 &= \sin\psi \sin i, \\ n_0 &= \cos i. \end{aligned} \tag{5}$$

The values of l, m, n depend naturally on the form of free surface of the primary star. If the latter is in equilibrium under the forces exerted upon it by its own rotation and the tidal action of its companion, its form can at present be predicted as far as its rotation is so slow that

[6] *Proc. Nat. Acad. Sci.* **28**, 133, 1942.

[7] *Cf. Proc. Amer. Philos. Soc.* **85**: 399–431, paragraph 4.

[8] It should be pointed out that the coefficient u and τ in paper I and the present study are not strictly the same. The present values of both coefficients will namely refer to the darkening in light of the absorption lines selected for measurements of the radial velocity, and may therefore differ from those in paper I which referred to the darkening in light between absorption lines at the effective wavelength of the photometric observations.

quantities smaller than squares of its angular velocity may be neglected, and as far as the disturbing action of the secondary component can be approximated by that of a mass-point. To this order of accuracy[9]

$$\frac{r-r_1}{r_1}=\frac{m_2}{m_1}\sum_{j=2}^{4}\Delta_j r_1^{j+1}P_j(\lambda)-\frac{\omega_1^2}{4\pi G\tilde{\rho}_1}\Delta_2 P_2(\nu), \quad (6)$$

where

r_1 = radius of a sphere of equal volume as the distorted primary and expressed in terms of the instantaneous separation of both components,
ω_1 = angular velocity of rotation of the primary star,
$\tilde{\rho}_1$ = mean density of the primary,
m_2/m_1 = mass-ratio of the two components,
Δ_j = constants depending on internal structure of the distorted primary star (for their definition, *cf.* reference 9),
G = constant of gravitation,

and the P's are Legendre polynomials of various orders, whose arguments

$$\begin{aligned}\lambda &= \cos\phi\sin\theta;\\ \mu &= \sin\phi\sin\theta,\\ \nu &= \cos\theta,\end{aligned} \quad (7)$$

are direction cosines of an arbitrary radius-vector in the XYZ-system. The distortion of the secondary component may be obtained from (6) by a mere interchange of subscripts.

The direction cosines of a line normal to the distorted surface specified by (6) are found to be

$$\begin{aligned}l &= \lambda\left\{1-v_1^{(2)}\nu^2+\left(\lambda-\frac{1}{\lambda}\right)\sum_{j=2}^{4}w_1^{(j)}P_j^1(\lambda)\right\},\\ m &= \mu\left\{1-v_1^{(2)}\nu^2+\lambda\sum_{j=2}^{4}w_1^{(j)}P_j^1(\lambda)\right\},\\ n &= \nu\left\{1-v_1^{(2)}\nu^2+v_1^{(2)}+\lambda\sum_{j=2}^{4}w_1^{(j)}P_j^1(\lambda)\right\},\end{aligned} \quad (8)$$

where accents on $P(\lambda)$ denote functional derivatives, and

$$v_{1,2}^{(j)}=\frac{3}{2}\Delta_j\frac{\omega_{1,2}^2}{2\pi G\tilde{\rho}_{1,2}}, \quad (9)$$

$$w_{1,2}^{(j)}=\frac{m_{2,1}}{m_{1,2}}\Delta_j r_{1,2}^{j+2}, \quad (10)$$

the subscripts 1, 2 referring to the primary (1) and secondary (2) component, respectively.[10] The variation of gravity over a surface specified by (6) is likewise found to be[9]

$$\frac{g-g_0}{g_0}=\frac{1}{3}v_1^{(2)}\left\{\frac{5}{\Delta_2}-1\right\}P_2(\nu)-\sum_{j=2}^{4}\left\{\frac{2j+1}{\Delta_j}-j+1\right\}w_1^{(j)}P_j(\lambda). \quad (11)$$

Equations (6), (8), and (11) are exact as far as quantities of the order of fifth powers of r_1 are concerned.

Combining equations (2)–(4) and (6) and making use of (8) and (11) we may ultimately express the light element (1) explicitly in terms of our polar coordinates. If we put, as customary,

$$dl=(1-u)(dl)^U+u(dl)^D, \quad (1.1)$$

where $(dl)^U$ and $(dl)^D$ denote the "uniform" and "completely darkened" part of the element, we obtain

$$(dl)^U=r_1^2H_0L\left\{1+\frac{1}{3}v_1^{(2)}\left[\left\{\tau\left(\frac{5}{\Delta_2}-1\right)-2\right\}P_2(\nu)+\left\{\frac{n_0}{L}-\nu\right\}P_2'(\nu)\right]-\sum_{j=2}^{4}w_j^{(j)}\left[\left\{\tau\left(\frac{2j+1}{\Delta_j}+1-j\right)-2\right\}P_j(\lambda)+\left\{\frac{l_0}{L}-\lambda\right\}P_j'(\lambda)\right]\right\}\sin\theta\,d\theta d\phi, \quad (12)$$

and

$$(dl)^D=r_1^2H_0L^2\left\{1+\frac{1}{3}v_1^{(2)}\left[\left\{\tau\left(\frac{5}{\Delta_2}-1\right)-2\right\}P_2(\nu)+2\left\{\frac{n_0}{L}-\nu\right\}P_2'(\nu)\right]-\sum_{j=2}^{4}w_1^{(j)}\left[\left\{\tau\left(\frac{2j+1}{\Delta_j}+1-j\right)-2\right\}P_j(\lambda)+2\left\{\frac{l_0}{L}-\lambda\right\}P_2(\lambda)\right]\right\}\sin\theta\,d\theta d\phi, \quad (13)$$

where we have abbreviated

$$L=\lambda l_0+\mu m_0+\nu n_0.$$

The non-orbital velocity V', in the line of sight, of any point on the star's surface remains to be specified. It follows from general geometrical considerations that, in the case of uniform rotation, this velocity should be proportional to the

[9] *Cf.*, for instance, Chandrasekhar, *Monthly Notices Roy. Astron. Soc.* **93**: 462, 539, 1933.

[10] If the components happen to rotate in synchronism with orbital revolution and ω_1 is equal to the Keplerian angular velocity, then

$$v_{1,2}=\left(1+\frac{m_{2,1}}{m_{1,2}}\right)\Delta_j r_{1,2}^{2+j}=\Delta_j r_{1,2}^{2+j}+w_{1,2}^{(j)} \quad (9.1)$$

distance at any point from the axis of rotation projected on the celestial sphere. This leads us to introduce another system of rectangular coordinates $X'Y'Z'$, fixed with respect to the observer and having again the origin at the center of mass of the primary star, but whose X'-axis is constantly coincident with the line of sight while Z' is in the direction of the projected center of the secondary component. The plane tangent to the celestial sphere at the origin of coordinates is evidently defined by $X' = 0$, and the radial velocity of any point at the primary's disk then assumes the form

$$V' = \pm \omega_1 \sin i(Z' \cos \eta - Y' \sin \eta), \quad (14)$$

where η denotes the angle between the projected axis of rotation and the Y'-axis. The sign in front of ω is positive if the axial rotation is direct and negative if it is retrograde. Since no instance of retrograde rotation has been detected so far among spectroscopic binaries, we shall hereafter work with the positive sign only.

The equation of surface of the distorted primary admits of the parametric representation

$$\frac{X'}{L} = \frac{Y'}{M} = \frac{Z'}{N} = r, \quad (15)$$

where L, M, N are direction cosines of any radius-vector in the primed system. These direction cosines can evidently be regarded as rectangular coordinates, in the primed system, over a sphere of unit radius. For reasons which will become apparent later we prefer, however, to retain the instantaneous separation of the components as our unit of length. In order to do so we have therefore to put

$$L = \frac{z}{r_1}, \qquad M = \frac{y}{r_1}, \qquad N = \frac{x}{r_1},$$

where r_1 denotes, as before, the mean fractional radius of the primary star, and adopt x, y, z as our new set of variables. Equation (14) then takes the alternative form

$$V' = \omega_1 R \sin i(x \cos \eta - y \sin \eta), \quad (14.1)$$

where R specifies the actual boundary of the distorted primary component in absolute units.

At this stage we are confronted with two tasks prerequisite to obtaining δV: to rewrite R and J in terms of x, y, z, and to specify the limits over which $V'dl$ and dl are to be integrated. The primed axes $X'Y'Z'$ referred to the original system are clearly specified by the scheme

	X'	Y'	Z'
X	l_0	l_1	l_2
Y	m_0	m_1	m_2
Z	n_0	n_1	n_2

where the new direction cosines of the respective axes are

$$l_1 = 0, \qquad m_1 = -\frac{n_0}{l_2}, \qquad n_1 = \frac{m_0}{l_2},$$

$$l_2 = \sqrt{1 - l_0^2}, \quad m_2 = -\frac{l_0 m_0}{l_2}, \quad n_2 = -\frac{l_0 n_0}{l_2}. \quad (16)$$

The angle η between the projected axis of rotation and the Y'-axis, in the $Y'Z'$-plane, is now easily obtained from

$$\sin \eta = \frac{\cos \psi \cos i}{l_2} \quad \text{and} \quad \cos \eta = \frac{\sin \psi}{l_2},$$

which reduces equation (14.1) to

$$V' = \omega_1 R(n_1 x + n_2 y), \quad (14.2)$$

in which form we are going to use it later on.

The direction cosines λ, μ, ν of a radius-vector in our original system are related with L, M, N by

$$\begin{aligned} \lambda &= l_0 L + l_1 M + l_2 N, \\ \mu &= m_0 L + m_1 M + m_2 N, \\ \nu &= n_0 L + n_1 M + n_2 N. \end{aligned}$$

By virtue of these relations the Legendre coefficients and their derivatives in (6), (8), or (11) may now be rewritten as polynomials of the j-th degree in terms of integral powers of x, y, z, with coefficients of such terms depending on the amount of distortion and the relative position of the components in their orbit. Since, furthermore,

$$r_1^2 \cos \gamma \sin \theta \, d\theta d\phi = dxdy,$$

the non-orbital radial velocity of a rotating distorted star then may be written as

$$\delta V = \frac{\int\int V' r^2 J dxdy}{\int\int r^2 J dxdy}, \quad (17)$$

where both integrands are known rational algebraic functions of x and y.

In order to be able to perform the integration we still have to specify the limits. The direction cosines L, M, N are known to satisfy the

relation

$$L^2 + M^2 + N^2 = 1. \tag{18}$$

It may be remembered that L, the cosine of the angle of foreshortening, vanishes at the visible limb of spherical stars and becomes a small quantity of the first order in the case of distortion. Since to the order of accuracy we are working squares of such quantities may be ignored, the intersection, with the xy-plane, of distorted surface of the primary component reduces to

$$x^2 + y^2 = r_1^2. \tag{19}$$

In consequence, the limits of double integration with respect to y and x in (17) out of eclipses become $\pm\sqrt{r_1^2 - x^2}$ and $\pm r_1$, respectively.

Should, however, our spectroscopic binary happen to be also an eclipsing variable, the definition of limits of integration during eclipses will require somewhat more caution. Within minima, the integrals in (17) are naturally to be extended over the area of the apparent disk visible at any particular moment only. For reasons which will become immediately apparent we prefer, however, to do so by performing the integration first over the whole disk, then over the eclipsed area, and subtracting both. The advantage of so doing rests on the fact that all respective integrals taken over the whole disk vanish or reduce to constants, so that we are left with those taken over the eclipsed area only. These latter integrals have, however, been exhaustively investigated in paper I in connection with theoretical light curves of close eclipsing systems. The results contained in paper I should in fact enable us now to write down the theoretical velocity curves of close binary systems almost at once. Nevertheless, in order to make their derivation more intelligible, we shall reproduce here briefly the way in which the limits of eclipsed areas of distorted stars are established.

The equation of the shadow-cylinder cast by the secondary (eclipsing) component in the direction of the line of sight is

$$(\delta - Z')^2 + Y'^2 = r_2^2(l + \Delta\bar{r}_2)^2, \tag{20}$$

where r_2 stands for the fractional radius of a sphere having the same volume as the secondary component; δ, the projected distance of centers of the two components and expressed in terms of their actual separation, is clearly given by

$$\delta^2 = \sin^2\psi \sin^2 i + \cos^2 i = l_2^2;$$

and $\Delta\bar{r}_2$, a measure of distortion of the secondary's shadow-cylinder, becomes, in conformity with (6),

$$\Delta\bar{r}_2 = \sum_{j=2}^{4} w_2^{(j)} P_j(\lambda') - \frac{1}{3} v_2^{(2)} P_2(\nu'), \tag{21}$$

where (since the axis of the shadow-cylinder is parallel to the line of sight)

$$\left.\begin{aligned} r_2\lambda' &= l_2(\delta - x), \\ r_2\nu' &= n_1\sqrt{r_2^2 - (\delta - x)^2} + n_2(\delta - x). \end{aligned}\right\} \tag{22}$$

The portion of the primary star eclipsed by the secondary can be considered as bound by two arcs: QRQ' and $QR'Q'$ (see the figure in paper I). To the order of accuracy we are working the former is a part of the circle defined by equation (19) while the equation of arc $QR'Q'$ should be obtained by solving equation of the secondary's shadow-cylinder with that of surface of the primary star. If we inset (15) in (20) then, to the first order in small quantities, the latter equation becomes

$$\begin{aligned}(\delta - x)^2 + y^2 = r_2^2(l + 2\Delta\bar{r}_2) \\ - 2\Delta r_1\{r_2^2 - \delta(\delta - x)\} + \cdots\end{aligned} \tag{23}$$

where

$$\Delta r_1 = \sum_{j=2}^{4} w_1^{(j)} P_j(\lambda'') - \frac{1}{3} v_1^{(2)} P_2(\nu''), \tag{24}$$

$$\left.\begin{aligned} r_1\lambda'' &= l_0\sqrt{2\delta(s-x)} + l_2 x, \\ r_1\nu'' &= n_0\sqrt{2\delta(s-x)} + n_1\sqrt{r_2^2 - (\delta - x)^2} + n_2 x, \end{aligned}\right\} \tag{25}$$

and where we have abbreviated

$$s = \frac{r_1^2 - r_2^2 + \delta^2}{2\delta}.$$

Let us now divide the total obscured area in two parts: $QRQ'S$ and $QR'Q'S$ (see again the figure). As long as the eclipse is partial, the former part is evidently limited by $\pm\sqrt{r_1^2 - x^2}$ in the y-coordinate, and between s and r_1 in x. It becomes equal to the entire area of the primary's disk if the eclipse is total, and vanishes if it is annular. If both components were spherical, the area of the remaining segment $QR'Q'S$ would be comprised between $\pm\sqrt{r_2^2 - (\delta - x)^2}$ in the y-coordinate, and from $\delta - r_2$ to s or $\delta + r_2$ in x, as to whether the eclipse is partial or annular. In close binary systems the arc

$QR'Q'$ will, however, deviate from the circle

$$(\delta - x)^2 + y^2 = r_2^2, \tag{26}$$

and this deviation, in y-coordinate, will amount to

$$\Delta y = \frac{r_2^2 \Delta r_2}{\sqrt{r_2^2 - (\delta - x)^2}} - \frac{[r_2^2 - \delta(\delta - x)]\Delta r_1}{\sqrt{r_2^2 - (\delta - x)^2}} + \cdots. \tag{27}$$

Thus in order to complete the eclipsed area, $2\Delta y$ is to be integrated with respect to x from $\delta - r_2$ to s if the eclipse is partial, and from $\delta - r_2$ to $\delta + r_2$ if it is annular. When the disk undergoing eclipse appears uniformly bright, the integrand of these "boundary corrections" consists solely of $2\Delta y$; when the disk is completely darkened at limb, this integrand is to be multiplied by the foreshortening factor $\sqrt{2\delta(s - x)}$. Since Δy is a small quantity of the first order, the effect of gravity-darkening upon the narrow strip of $\Delta y dx$ need not evidently be considered.

III. THEORETICAL VELOCITY CURVES WITHIN MINIMA

The theoretical contribution δV to the observed radial velocity arising from axial rotation of a distorted star undergoing eclipse may now be obtained as follows. The denominator on the right-hand side of equation (17) denotes nothing else but the light of the visible portion of the component under consideration; and as such it may be written as

$$\iint dl = \pi r_1^2 H_0 \{(1 - u) \times [\Delta\mathfrak{L}^U(k, -1) - \Delta\mathfrak{L}^U(k, p)] + \frac{2}{3} u[\Delta\mathfrak{L}^D(k, -1) - \Delta\mathfrak{L}^D(k, p)]\}, \tag{28}$$

where $\Delta\mathfrak{L}(k, p)$ stands for the loss of light of the eclipsed star at any particular phase, and $\Delta\mathfrak{L}(k, -1)$ for that at the beginning of totality (i.e., for the whole light of the primary star). The $\Delta\mathfrak{L}$'s in the above equation are identical with those denoted by the same symbols and defined by equations (66) of paper I. Their explicit forms are rather long and unattractive; but since they all have been given in part V of paper I there is no need to reprint them at present.

The numerator in (17) can be arrived at by essentially similar methods. Before doing so it is useful to recall that $ydxdy$ vanishes when integrated over any area symmetrical with respect to the y-axis. This makes it evident that the term, in V', varying as $n_2 y$ (equation 14.2) will contribute nothing to the observed radial velocity except in connection with the rotational distortion of the eclipsed star.[11] Let us now revert to our original notations and write (17) in the form

$$\delta V = \frac{(1 - u)\iint V'(dl)^U + u\iint V'(dl)^D}{\text{light of the visible portion}}, \tag{17.1}$$

where the denominator is defined by (28), and put, for brevity's sake,

$$\iint V'(dl)^{U,D} = (\pi\omega_1 r_1^2 R_1 H_0) A^{U,D}, \tag{29}$$

where

$$A^{U,D} = g_*^{U,D}(k, -1) - g_*^{U,D}(k, p) - g_1^{U,D}(k, p) - g_2^{U,D}(k, p) \tag{30}$$

and R_1 stands for the mean radius of the distorted primary component in absolute units, related with its fractional radius r_1 by

$$\frac{R - R_1}{R_1} = \frac{r - r_1}{r_1}.$$

In analogy with paper I, the $g^{U,D}$'s in equation (30) will summarize effects of the "circular integrals" (i.e., those taken over the area bounded by the two circles defined by equations (19) and (26)), while $g_{1,2}^{U,D}$ will account for effects of the "boundary corrections" obtained by integrating Δy from (27). The former may again be expressed in terms of "associated alpha-functions" $\alpha_n^m(k, p)$ of order m and index n, introduced in paper I and defined by

$$\pi r_1^{m+n+2}\alpha_n^m = \left\{\int_s^{r_1}\int_{-\sqrt{r_1^2 - x^2}}^{+\sqrt{r_1^2 - x^2}} + \int_{\delta - r_2}^{s}\int_{-\sqrt{r_2^2 - (\delta - x)^2}}^{+\sqrt{r_2^2 - (\delta - x)^2}}\right\} x^m z^n dxdy \tag{31.0}$$

if the eclipse is partial, and

$$\pi r_1^{m+n+2}\alpha_n^m = \int_{\delta - r_2}^{\delta + r_2}\int_{-\sqrt{r_2^2 - (\delta - x)^2}}^{+\sqrt{r_2^2 - (\delta - x)^2}} x^m z^n dxdy \tag{31.1}$$

if it is annular.[12] Then, for uniformly bright

[11] The reason being that λ, unlike ν, does not contain y explicitly.

[12] It may be recalled that, by virtue of (18), $z^2 = r_1^2 - x^2 - y^2$.

disks,

$$
\begin{aligned}
g_*^U(k,p) = &\left\{ \Omega_2 \left[(n_0^2 - n_1^2)\alpha_2^1 + (n_2^2 - n_1^2)\alpha_0^3 + 2n_0n_2\alpha_1^2 + \frac{2}{3}P_2(n_1)\alpha_0^1 \right] \right. \\
&\left. + \frac{2}{3}P_2(n_0)\alpha_0^1 + n_0n_2\alpha_{-1}^2 \right\} n_1v_1^{(2)} + \{(\Omega_2 - 2)[n_0(\alpha_1^0 - \alpha_1^2 - \alpha_3^0) \\
&+ n_2(\alpha_0^1 - \alpha_0^3 - \alpha_2^1) + n_0(\alpha_{-1}^0 - \alpha_{-1}^2 - \alpha_1^0)\} n_1n_2v_1^{(2)} \\
&- \left\{ \frac{\Omega_2}{2}[3l_0^2\alpha_2^1 + 6l_0l_2\alpha_1^2 + 3l_2^2\alpha_0^3 - \alpha_0^1] + 2P_2(l_0)\alpha_0^1 + 3l_0l_2\alpha_{-1}^2 \right\} n_1w_1^{(2)} \qquad (32) \\
&- \left\{ \frac{\Omega_3}{2}[5l_0^3\alpha_3^1 + 15l_0^2l_2\alpha_2^2 + 15l_0l_2^2\alpha_1^3 + 5l_2^3\alpha_0^4 - 3l_0\alpha_1^1 - 3l_2\alpha_0^2] \right. \\
&\left. + [l_0\alpha_1^1 + 2l_2\alpha_0^2]P_3'(l_0) - \frac{3}{2}l_0\alpha_1^1 + \frac{3}{2}l_0[5l_2^2\alpha_{-1}^3 - \alpha_{-1}^1] \right\} n_1w_1^{(3)} \\
&- \left\{ \frac{\Omega_4}{8}[35l_0^4\alpha_4^1 + 140l_0^3l_2\alpha_3^2 + 210l_0^2l_2^2\alpha_2^3 + 140l_0l_2^3\alpha_1^4 + 35l_2^4\alpha_0^5 - 30l_0^2\alpha_2^1 \right. \\
&- 60l_0l_2\alpha_1^2 - 30l_2^2\alpha_0^3 + 3\alpha_0^1] + l_0P_4'(l_0)\alpha_2^1 + \frac{15}{2}l_2^2(7l_0^2 - 1)\alpha_0^3 - P_3'(l_0)\alpha_0^1 \\
&\left. + \frac{5}{2}l_0l_2[3(7l_0^2 - 2)\alpha_1^2 + 7l_2^2\alpha_{-1}^4 - 3\alpha_{-1}^2] \right\} n_1w_1^{(4)} + \cdots + \alpha_0^1,
\end{aligned}
$$

where we have abbreviated

$$\Omega j = \left\{ \frac{2j+1}{\Delta j} + 1 - j \right\} \tau - j - 3.$$

The explicit expression for $g_*^D(k, p)$ may be obtained by increasing, in (32), simply the indices of all associated α-functions by unity, replacing Ωj by $\frac{1}{2}(\Omega j - j)$ and multiplying small terms on the right-hand side by two.

The effects of the "boundary corrections" $g_{1,2}^U$ may ultimately be written as

$$
\begin{aligned}
g_1^U(k,p) = &\left\{ n_0^2\Im_{-1,2}^1 + n_1^2\Im_{1,0}^1 + n_2^2\Im_{-1,0}^3 + 2n_0n_2\Im_{-1,1}^2 - \frac{1}{3}\Im_{-1,0}^1 \right\} n_1v_1^{(2)} \\
&+ 2\{n_0\Im_{1,1}^0 + n_2\Im_{1,0}^1\} n_1n_2x_1^{(2)} - \{3l_0^2\Im_{-1,2}^1 + 6l_0l_2\Im_{-1,1}^1 + 3l_2^2\Im_{-1,0}^2 - \Im_{-1,0}^0\} n_1w_1^{(2)} \\
&- \{5l_0^3\Im_{-1,3}^1 + 15l_0^2l_2\Im_{-1,2}^2 + 15l_0l_2^2\Im_{-1,1}^3 + 5l_2^3\Im_{-1,0}^4 \qquad (33) \\
&\quad - 3l_0\Im_{-1,1}^1 - 3l_2\Im_{-1,0}^2\} n_1w_1^{(3)} \\
&- \frac{1}{4}\{35l_0^4\Im_{-1,4}^1 + 140l_0^3l_2\Im_{-1,3}^2 + 210l_0^2l_2^2\Im_{-1,2}^3 + 140l_0l_2^3\Im_{-1,1}^4 + 35l_2^4\Im_{-1,0}^5 \\
&\quad - 30l_2^2\Im_{-1,2}^1 - 60l_0l_2\Im_{-1,1}^2 - 30l_2^2\Im_{-1,0}^3 + 3\Im_{-1,0}^1\} n_1w_1^{(4)} + \cdots,
\end{aligned}
$$

$$
\begin{aligned}
g_2^U(k,p) = &- \{n_1^2\Re_{1,0}^1 + n_2^2\Re_{-1,0}^3 - \Re_{-1,0}^1\} n_1v_2^{(2)} - \frac{2n_1n_2}{\pi r_1^2 r_2}v_2^{(2)}J_{1,0}^1 \\
&+ \{3l_2^2\Re_{-1,0}^3 - \Re_{-1,0}^1\} n_1w_2^{(2)} + \{5l_2^3\Re_{-1,0}^4 - 3l_2\Re_{-1,0}^2\} n_1w_2^{(3)} \qquad (34) \\
&+ \frac{1}{4}\{35l_2^4\Re_{-1,0}^5 - 30l_2^2\Re_{-1,0}^3 + 3\Re_{-1,0}^1\} n_1w_2^{(4)} + \cdots
\end{aligned}
$$

where

$$\pi r_1^q \mathfrak{I}^m_{\beta,\gamma} = (r_2^2 - \delta^2) I^m_{\beta,\gamma} + \delta I^{m+1}_{\beta,\gamma}, \quad (35)$$

$$\pi r_1^2 r_2^{q-4} \mathfrak{R}^m_{\beta,\gamma} = - J^m_{\beta,\gamma} + \delta J^{m-1}_{\beta,\gamma}, \quad (36)$$

and

$$I^m_{\beta,\gamma} = \int_{c_1}^{c_2} [r_2^2 - (\delta - x)^2]^{\beta/2} \times [2\delta(s - x)]^{\gamma/2} x^m dx, \quad (37.0)$$

$$J^m_{\beta,\gamma} = \int_{c_1}^{c_2} [r_2^2 - (\delta - x)^2]^{\beta/2} \times [2\delta(s - x)]^{\gamma/2} [\delta - x]^m dx, \quad (37.1)$$

where

$$q = \beta + \gamma + m + 3$$

and

$$c_1 = \delta - r_2,$$

$$c_2 = s \quad \text{or} \quad \delta + r_2,$$

depending on whether the eclipse is partial or annular. Appropriate expressions for $g^p_{1,2}(k, p)$ may again be obtained from (33) or (34) by increasing the superscripts of all respective boundary integrals by unity.

The reader may also verify that the terms, in g, arising from tidal distortion of the primary component may be directly obtained from the corresponding expressions for f (*cf.* equations (66) and later of paper I), which constitute the theoretical light curves and thus the denominator of (17.1), by increasing the orders or superscripts of all respective functions by unity, replacing Ω_j by $\Omega_j - 1$, and multiplying by n_1 for uniformly bright stars or by $\frac{2}{3}n_1$ for those completely darkened at limb. The rotational terms as well as those due to the distortion of the eclipsing component are, however, quite different.

The associated α-functions as well as boundary integrals defined by equations (37) have been exhaustively investigated in parts IV and VI of paper I, so that their forms may at present be regarded as known. They all turn out to be functions of two independent variables which are customarily taken to be the ratio of radii k of both components and the geometrical depth p of the eclipse, defined by

$$k = \frac{r_s}{r_l} \quad \text{and} \quad p = \frac{\delta - r_l}{r_s},$$

where r_l and r_s stand for fractional radii of the larger and the smaller component, respectively. The ratio of radii k is constrained, by definition, to values between zero and unity; while p is normalized so as to vary from $+1$ at the moment of first contact to -1 at the beginning of totality or annular phase. All associated α-functions as well as boundary integrals vanish when $p = 1$. The boundary integrals and associated α-functions of odd orders vanish likewise at the beginning of totality; while those of zero or even orders reduce then to constants.

If both components were spherical then (remembering that $\alpha_0^0(k, -1) = 1$ and $\alpha_1^0(k, -1) = \frac{2}{3}$) equation (17.1) would simplify to

$$\frac{\delta V}{\omega_1 R_1} = -\frac{n_1\{(1-u)\alpha_0^1 + u\alpha_1^1\}}{(1-u)(1-\alpha_0^0) + u\left(\frac{2}{3} - \alpha_1^0\right)}, \quad (38)$$

which, for uniformly bright disks, would reduce further to

$$\frac{\delta V}{\omega_1 R_1} = -\frac{n_1 \alpha_0^1}{1 - \alpha_0^0}. \quad (38.1)$$

These equations have been previously derived by the writer[6] and are simple enough. An appearance of distortion of the components will affect their velocity curves within eclipses in much the same way as their light curves: a considerable number of additional terms appear which greatly complicate the situation.

The right-hand side of the complete equation (17.1) then consists of two types of quantities: the direction cosines l_0, m_0, n_0 which depend on the scale of each individual system, and the functions α^m_n, $I^m_{\beta,\gamma}$, and $J^m_{\beta,\gamma}$ which depend only on the geometry of eclipses. An evaluation of the values of direction cosines of the line of sight at any particular phase represents certainly a trivial task. The computation of the associated α-functions or of the boundary integrals seems, on the other hand, prohibitively complicated—in fact so complicated that the results derived above are likely to remain of little practical use until the respective functions have been tabulated in terms of k and p within the whole domain of practical interest.[13] But once this has been done, the equations given in this paper should make it practicable to predict the theoretical velocity curves of close eclipsing systems to a

[13] It may be pointed out that for the two lowest associated α-functions, namely α_0^0 and α_1^0, adequate tables already exist. As the reader may easily verify, α_0^0 stands for nothing else but the fractional loss of light during eclipse of a uniformly bright disk (equal to the fractional area eclipsed), while $\frac{2}{3}\alpha_1^0$ represents the corresponding loss of light of a disk completely darkened at limb. Extensive and accurate tables of both these functions, published recently by Zessewitsh, *Bull. Astr. Inst. Leningrad*, No. 45 (1939) and No. 50 (1940), should be sufficient for a long time to come.

high degree of accuracy and to compare them with observations. The fact that tables of the same functions are also required for rigorous interpretation of light curves of close eclipsing systems should provide an additional stimulus for their construction; and it is to be hoped that such a task may be undertaken and brought to a completion in not too distant future.

The quantity $\delta V/\omega_1 R_1$ on the left-hand side of equation (17.1) is in astronomical literature frequently referred to as the "rotation factor." Provided that its numerical values, during an eclipse, are determined by means of equation (17.1), the non-orbital radial velocity δV observed at any phase should lend itself to a determination of the velocity $\omega_1 R_1$ at the equator of the component undergoing eclipse or—if ω_1 is identified with say the Keplerian angular velocity—of its mean radius R_1 in absolute units.

In attempts to apply such a procedure to practical cases it should, however, be borne in mind that the derivation of equation (17.1) involves two simplifying assumptions: namely that the star undergoing eclipse rotates like a rigid body, and that its axis of rotation remains constantly perpendicular to the orbital plane. Neither of these assumptions needs necessarily to be fulfilled in every practical case. It is known, for instance, that the equatorial regions of our sun rotate approximately 10 per cent faster than regions near its poles, and the same situation may be still enhanced in rapidly rotating components of close eclipsing systems. The equatorial velocities obtained from our above theory should then represent only certain means of actual angular velocities of the primary component at different astrocentric latitudes, which may either exceed, or be smaller than, the actual velocity at its equator—depending on circumstances of the eclipse. On the other hand, provided that the law of variation of the angular velocity with latitude were known from the theory, it could be readily incorporated in the derivation of our equation (17.1); or, *vice versa*, accurate observations of δV might enable us to obtain some empirical information concerning the variation of angular velocity with latitude for stars other than the sun.

The assumption that the axis of rotation of the component undergoing eclipse remains perpendicular to the orbital plane can likewise be certainly justified on grounds of simplicity; but its actual validity may sometimes be open to doubt. For if say the tides raised by the eclipsing component at the surface of its massive mate are small, no *a priori* reason is known which should impel the massive star to keep its axis of rotation exactly perpendicular to the orbital plane. A deviation from perpendicularity would, moreover, entail no observational consequences that could be detected otherwise than by the study of the "rotational effect." That is, if the axis of rotation were inclined to the plane of the orbit, the rotational effect should no longer be symmetrical with respect to the moment of conjunction, and need not be zero at mid-primary minimum. This asymmetry of the rotational effect should, furthermore, vanish and reappear periodically as the apparent inclination of the axis of rotation oscillates during precessional motion of the rotating star. There appears to be some observational evidence that such a situation may be realized, for instance, in the Algol system.[14]

IV. THEORETICAL VELOCITY CURVES OUT OF ECLIPSES

Let us now suppose that the primary component has emerged from the eclipse and both stars shine in full light. The question arises then as to the contributions, to observed radial velocities, due to axial rotation of distorted components between minima—a practically much more general case because it will apply to all close spectroscopic binaries regardless of whether or not they happen to be also eclipsing variables. From a purely analytical point of view, the treatment of velocity curves of distorted components in full light is greatly simplified because the limits of integration in both coordinates now become symmetrical. In fact, since out of eclipses all boundary integrals vanish identically, the numerator in (17.1) reduces immediately to

$$\iint V'dl = \pi\omega_1^2 r_1^2 R_1 H_0 \times\{(1-u)g_*^U(k,-1)+ug_*^D(k,-1)\}, \quad (39)$$

i.e., turns out expressible in terms of associated α-functions only. It is known, however, that all such functions of odd orders vanish when integrated over the whole disk, while those of zero or even order reduce to constants defined by[15]

$$\alpha_{2\nu}^{2\mu}(k,-1) = \frac{\nu!\Gamma\left(\mu+\frac{1}{2}\right)}{\sqrt{\pi}(\mu+\nu+1)!}, \quad (40.0)$$

[14] *Cf.* Kopal, *Astrophys. Jour.* **96**: 399, 1942 (part IV).

[15] *Cf.* paragraph 18 of *Proc. Amer. Philos. Soc.* **85**: 399–431.

or $\left.\begin{matrix}\mu\\ \nu\end{matrix}\right\} = 0, 1, 2, \cdots$

$$\alpha_{2\nu-1}^{2\mu}(k, -1) = \frac{\Gamma\left(\mu+\frac{1}{2}\right)\Gamma\left(\nu+\frac{1}{2}\right)}{\sqrt{\pi}\,\Gamma\left(\mu+\nu+\frac{3}{2}\right)}, \qquad (40.1)$$

as to whether their index is even or odd.

The right-hand side of (39) will now depend on the phase only through the direction cosines of the line of sight. The reader may remember that the only two associated α-functions occuring in g_*^U or g_*^D with coefficients of zero order of magnitude are $\alpha_0{}^1$ and $\alpha_1{}^1$—both of which vanish when integration is extended over the whole disk. In consequence, the entire numerator in (17.1) out of eclipses becomes a small quantity of the first order. If so, however, then to the order of accuracy we are working similar quantities in the denominator of (17) may be ignored and the denominator itself reduces to

$$\int\int dl = \pi r_1{}^2 H_0\left(1 - \frac{u}{3}\right). \qquad (41)$$

If we divide now (39) by (41) and use the explicit forms of the g_*'s, the non-orbital contributions to radial velocities of components of close spectroscopic binaries in full light are easily evaluated. Let us put, as in the theory of the light curves,

$$\delta V = \frac{3(1-u)}{3-u}(\delta V)^U + \frac{2u}{3-u}(\delta V)^D, \qquad (42)$$

where $(\delta V)^U$ and $(\delta V)^D$ stand for the respective contributions of a uniformly bright star and one completely darkened at limb. Then after some elementary operations we establish that, correctly to terms of the fifth order in fractional radius of the distorted primary component,

$$\left(\frac{\delta V}{\omega_1 R_1}\right)^U = -\frac{2}{15} w_1{}^{(2)} \beta_2 m_0 P_2'(l_0) - \frac{w_1{}^{(3)}}{24}(\beta_3 + 6) m_0 P_3'(l_0) - \cdots \qquad (43.0)$$

and

$$\left(\frac{\delta V}{\omega_1 R_1}\right)^D = -\frac{1}{8} w_1{}^{(2)}(\beta_2 - 1) m_0 P_2'(l_0) - \frac{2}{35} w_1{}^{(3)}(\beta_3 + 5) m_0 P_3'(l_0) - \frac{w_1{}^{(4)}}{64}(\beta_4 + 13) m_0 P_4'(l_0) - \cdots \qquad (43.1)$$

where accents on P denote again derivatives with respect to l_0, and where we have abbreviated

$$\beta_j = \left\{\frac{2j+1}{\Delta_j} + 1 - j\right\}\tau. \qquad (44)$$

A combination of the foregoing equations may be ultimately written in the symmetric form

$$\delta V = -\omega_1 R_1 m_0 \sum_{j=2}^{4} w_1{}^{(j)} f_j P_j'(l_0), \qquad (45)$$

where

$$f_2 = \frac{8\beta_2 - 3u\beta_2 - 5u}{20(3-u)}, \qquad (46.0)$$

$$f_3 = \frac{210 + 35\beta_3 - 3u\beta_3 - 50u}{280(3-u)}, \qquad (46.1)$$

$$f_4 = \frac{u(\beta_4 + 13)}{32(3-u)}, \qquad (46.2)$$

are coefficients depending on the distribution of surface brightness and internal structure of the distorted primary star. The non-orbital contributions to the radial velocity of the secondary component are easily obtained from equations (43) or (45) by interchanging appropriate indices and shifting phase by 180°.

An inspection of the foregoing results reveals, first, that the non-orbital contributions to radial velocities of rotating components of close binary systems are due to their tidal distortion alone. This could perhaps have been anticipated because, out of eclipses, the aspect of a rotational ellipsoid does not change, to a distant observer, in the course of a revolution. That, furthermore, the rotation of a uniformly bright ellipsoid gives likewise rise to no variation of its radial velocity has been generally known. If, however, there is some limb- or gravity-darkening (or both), equation (45) shows that δV does not vanish—a fact first pointed out by Sterne.[2] Proceeding further to consider the effects of tidal harmonic distortion of order higher than the second, we notice that the third harmonic would contribute to the radial velocity of a rotating distorted ellipsoid even if the latter were uniformly bright—as a consequence of the fact that, in the course of a revolution, the center of light of so distorted a star would no longer project itself constantly on its center of mass. The limb- and gravity-darkening, if any, would merely reinforce this contribution. Ultimately we notice that the fourth-harmonic tidal distor-

tion of a rotating star will contribute nothing to its radial velocity unless the star exhibits some darkening at limb.

A closer examination of the coefficients f defined by equations (46) leads to certain interesting conclusions regarding the character of isophotae on apparent disks of the distorted stars. The coefficient f_2 may be evidently either positive or negative—depending on whether the limb- or gravity-darkening preponderate—and vanishes when

$$\beta_2 = \frac{5u}{8 - 3u} \quad \text{or} \quad u = \frac{8\beta_2}{5 + 3\beta_2}. \quad (47)$$

If this is the case, however, then also δV vanishes for ellipsoidal configurations; and we know on general grounds that this may happen if and only if the isophotae on the apparent disk form a family of curves constantly symmetrical with respect to the projected center of mass of the respective star. We infer therefrom at once that, to every coefficient of limb-darkening of a rotating ellipsoid there corresponds a certain amount of gravity-darkening, defined by equations (47), which will render the isophotae on its apparent disk at any phase symmetrical with respect to its center. The curves defined by such isophotae for an arbitrary value of u need not necessarily be closed—in fact they do freely cross the boundary of the apparent disk.

A case of special interest arises when $u = 1$. By clamping down full limb-darkening we may compel the boundary to become an envelope of all isophotae of finite surface brightness. If, in addition, $\beta_2 = 1$ the isophotae must form a family of curves symmetrical with respect to the projected center of mass of our ellipsoid; and since for $u = 1$ the limb itself has become an isophote corresponding to $J = 0$, all isophotae interior to it must represent a family of ellipses similar to the limb and concentric with it. That this is needed the case has recently been pointed out by Russell,[16] who arrived at this result by an entirely different type of analysis. When, ultimately, $\beta_2 > 1$, equations (47) make it evident that the symmetry of isophotae is definitely lost and no amount of limb-darkening may help to restore it.[17]

If we proceed further to consider terms associated with tidal distortion of the order higher than the second we notice that, unlike f_2, the coefficient f_4 does not vanish unless the star exhibits no darkening at limb and f_3 would fail to vanish even then—which indicates that under no circumstances can the isophotae on apparent non-uniform disks of distorted ellipsoids form a family of curves symmetrical with respect to their projected center of mass—whatever their amount of limb- or gravity-darkening.

V. INFLUENCE OF TIDAL DISTORTION UPON ELEMENTS OF SPECTROSCOPIC ORBITS

In order to investigate the significance of the foregoing results and their bearing upon determination of orbital elements of close spectroscopic binaries, let us compare equations (43) or (45) with the radial velocity V of the primary component around the center of mass of the binary system. As is well known,

$$V = \gamma + K_1[e \cos \tilde{\omega} + \cos (v + \tilde{\omega})], \quad (48)$$

where γ denotes the systemic radial velocity; K_1, the amplitude of the primary's orbital velocity-curve; e, the eccentricity of the orbit; v, the true anomaly; and $\tilde{\omega}$, the longitude of periastron measured from ascending node. If the eccentricity is small, $\tilde{\omega} + v$ may be conveniently expanded in terms of the mean anomaly M in a series whose first term, $\tilde{\omega} + M$, specifies the mean longitude which we shall hereafter denote by L. To the first order in e, equation (48) may then be expanded as

$$V = \gamma + K_1 \cos L + K_1 e \sin \tilde{\omega} \sin 2L + K_1 e \cos \tilde{\omega} \cos 2L + \cdots \quad (48.1)$$

and, to the same order of accuracy,

$$K_1 = \frac{m_2}{m_1 + m_2} \mu a_1 \sin i,$$

where a_1 is the mean radius, in absolute units, of the relative orbit of both components and μ denotes the mean daily motion.

In all preceding sections the primary component was supposed to be at rest at the origin of coordinates, and ψ stood for the true anomaly of the secondary star reckoned from inferior conjunction. For the sake of comparison with spectroscopic orbits, in which the primary is supposed to revolve, we now have to put $\psi = \tilde{\omega} + v - 90°$, in consequence of which $L = M + 90°$. Then

$$l_0 = \sin L \sin i,$$

$$m_0 = -\cos L \sin i,$$

[16] *Astrophys. Jour.* **95**: 345, 1942.

[17] It should be emphasized that, for real stars, there is every reason to expect that $\beta_2 \gg 1$.

and, as the reader may easily verify,

$$m_0P_2'(l_0) = -\frac{3}{2}\sin^2 i \sin 2L,$$

$$m_0P_3'(l_0) = -\frac{3}{8}(1-5\cos^2 i)\sin i\cos L + \frac{15}{8}\sin^3 i\cos 3L,$$

$$m_0P_4'(l_0) = -\frac{5}{8}(3-7\cos^2 i)\sin^2 i\sin 2L + \frac{35}{16}\sin^4 i\sin 4L.$$

In slightly eccentric orbits we may also identify the angular velocity ω_1 of rotation of the primary star with its mean daily motion. Since, furthermore, $(R_1/a_1) = r_1$, the non-orbital contribution δV to the observed radial velocity of the primary component, rewritten in terms of the mean longitude L, assumes ultimately the form

$$\delta V=\frac{1}{16}\{6(1-5\cos^2 i)w_1^{(3)}f_3\cos L+2[12w_1^{(2)}f_2 +5(3-7\cos^2 i)w_1^{(4)}f_4]\sin i\sin 2L -30w_1^{(3)}f_3\sin^2 i\cos 3L -35w_1^{(4)}f_4\sin^3 i\sin 4L+\cdots\}\times\left(1+\frac{m_1}{m_2}\right)r_1K_1\sin i. \quad (49)$$

Now the observable radial velocity of the primary component is evidently $V + \delta V$. Let us assume, for the sake of simplicity, that the real orbit of its center of mass is circular so that $V = \gamma + K_1\cos L$. The coefficient of $\cos L$ as derived from the observed velocity-curve of a tidally distorted star will, however, be not K_1, but

$$\left\{1+\frac{3}{8}r_1w_1^{(3)}\left(1+\frac{m_1}{m_2}\right)\times(1-5\cos^2 i)f_3\sin i+\cdots\right\}K_1. \quad (50)$$

The third-harmonic tidal distortion of components in close binary systems will therefore tend to increase or diminish the true amplitudes of their radial-velocity variation, depending on whether $\cos i \gtrless 1/\sqrt{5}$. For high values of orbital inclinations, such as are common among ordinary eclipsing systems, the true amplitudes should be smaller than the observed ones; for low inclinations the converse should be true. For the limiting value of $i = \cos^{-1}(1/\sqrt{5})$ or 63°.435 . . ., the first-order effect of tidal distortion upon K_1 should disappear. The second-order effect, neglected in (50), would arise from fifth harmonic distortion and be of the order of magnitude of $r_1w_1^{(5)}$ or r_1^7. The expression (50) can therefore be regarded as correct as far as terms of the order of r_1^6 are concerned. It may be added that, in ordinary eclipsing systems, the tidal distortion will thus tend to offset a spurious decrease of K_1 due to the reflected radiation;[18] but since this latter effect is of the order of r_1^3 as compared with r_1^5 of the tidal effect, it is evident that in most eclipsing systems the reflection will predominate and the neutralization will be far from complete.

Secondly, the term in (49) varying as $\sin 2L$ should evidently simulate a spurious orbital eccentricity. A comparison of equations (48.1) and (49) reveals that, to a first approximation, the effects of tidal distortion upon velocity-curves of close binary systems are such as to lead the orbit computer to a slightly eccentric orbit specified by

$$e=\frac{1}{8}\{12w_1^{(2)}f_2+5(3-7\cos^2 i)w_1^{(4)}f_4+\cdots\}\times\left(1+\frac{m_1}{m_2}\right)r_1\sin^2 i, \quad (51)$$

and $\bar{\omega} = 90°$ or 270° as to whether f_2 is positive or negative. The fourth harmonic distortion will tend to reinforce or diminish the eccentricity-simulating effects of the second harmonic, depending on whether $\cos i \gtrless \sqrt{3/7}$.

It should be stressed, however, that the foregoing value of spurious eccentricity of tidal origin may be regarded as correct to a first approximation only; for the correspondence between the respective terms in (48) and (49) fails when squares of orbital eccentricity in (48.1) are taken into account. An absence, from (49), of terms varying as cosines of even multiples of the mean longitude (or sines of its odd multiples) proves that any spurious deformation of radial-velocity orbits of tidally-distorted components are bound to be symmetrical with respect to the line of sight. The spurious longitude of periastron of such orbits would therefore remain 90° or 270°; but the amounts of spurious eccentricity as derived from higher individual terms should generally differ. It may be added again that in real binary systems, the

[18] *Cf.* reference 3, paragraph 9.

eccentricity-simulating effects of tidal distortion are bound to superpose upon equally spurious eccentricity due to the reflected radiation which leads to $\bar{\omega} = 270°$.[18] Only a resultant of the two is observable; and since the tidal $\bar{\omega}$ is ordinarily equal to 90° and the magnitudes of spurious reflection and tidal eccentricities are of the order of r_1^3 and r_1^4, respectively, the match of the two in practical cases may sometimes become quite close.

In dealing with two-spectra close binaries it should be also borne in mind that the spectroscopic values of e and $\bar{\omega}$ as deduced from observed radial velocities of their components without regard to the ellipticity or reflection need not in general be identical. In particular, if the orbits are really circular and the perturbations of radial velocities are due wholly to axial rotation of distorted components, the spurious $\bar{\omega}$'s of their absolute orbits should differ by 180°.

If, on the other hand, the real orbits of the components cease to be circular, the spurious e's arising from the ellipticity or reflection should be expected to combine with the real orbital e to yield a resultant which may be either larger or smaller than the real e. The general situation then becomes too complex to be analyzed in simple terms. In order to avoid such complications, it is recommended that *the theoretical contributions, to radial velocities, arising from both the ellipticity and reflection be taken out from measured velocities of components of close binary systems before a conventional solution for orbital elements is carried out.* In systems which happen to be also eclipsing variables all quantities constituting δV may be obtained from an analysis of their light curves; while in non-eclipsing systems the magnitude of certain factors must be estimated. But it is essential that such estimates be done and that the observed radial velocities are freed from effects of non-orbital origin; for only then elements of spectroscopic orbits may be obtained that are reasonably free from any obvious source of systematic errors.

THE ARABIC BILINGUAL ENTAGION

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ABSTRACT

The word ἐντάγιον is regularly used in Byzantine papyri in the sense of "receipt." This cannot have been the original meaning, for ἐντάσσω, from which it is derived, could not yield such a sense and actually occurs as "to requisition." In fact there are some instances in Byzantine papyri of the word ἐντάγιον itself meaning an order for payment, which was clearly its original sense. The evolution must have been "order for payment," "receipted order," "receipt." The original sense is that in which the word occurs in the letters of the Arab Governor of Egypt, Kurrah b. Sharīk from Aphrodito. An *entagion* is there an order for the payment of taxes, the delivery of supplies, or the execution of work, addressed to the people of a village or other locality and enclosed with the Governor's letter (to the pagarch) in which the service was ordered. The orders to the individual taxpayer were issued by the pagarch. There was a difference of form between the *entagion* and the letter to a pagarch: the latter was sent in duplicate, Arabic and Greek in separate rolls, whereas in the *entagion* Arabic and Greek were in the same roll. Moreover the letters to pagarchs were written in a sloping cursive hand with hardly any abbreviations, the *entagia* in minuscules, freely abbreviated. At 'Auja Ḥafīr in Palestine the Colt Expedition discovered a quantity of Greek and Arabic papyri which included seven *entagia*, here published in full, which, despite certain differences in detail, show a remarkable resemblance in form and arrangement to the somewhat later Egyptian examples. Clearly the same general scheme was employed in various provinces of the Arab Empire. This fact is most plausibly explained as due to borrowing from the Byzantine practice, and it is likely that the form of the *entagion* was evolved within the Byzantine Empire before the Arab conquest. As there appear to be no actual examples of Byzantine *entagia* of a form closely similar (except for the use of Arabic) to those of Arab times, it may be that the form was evolved not in Egypt but in some other province, e.g. Syria, was there borrowed by the Arabs and by them introduced into Egypt.

The word *entagion* is of frequent occurrence in the papyri of the Byzantine period, usually in the sense of "receipt." That this was not the original meaning is clear from the etymology of the word; and in fact there are in Byzantine papyri a few instances of its use in a different and obviously earlier connotation. It is this earlier meaning which, superseded in the majority of our Byzantine papyri, reappears in the letters of Ḳurrah b. Sharīk, the Arab Governor of Egypt, to the pagarch of Aphrodito.

A few quotations will illustrate the usage. In PLond.[1] IV, 1335, the Governor writes: "We have ordered from your administrative district 2000 artabas of wheat, and having made out the *entagia* for these to the people of the localities have sent them to you."[2] In 1378, "we have ordered palm-beams and other articles . . . and having made out the *entagia* for these to the people of the localities have sent them to you."[3] In 1369, "we have sent up to you four quintals

[1] The following abbreviated references are used in this article:

JEA = *Journal of Egyptian Archaeology.*

PERF = *Papyrus Erzherzog Rainer: Führer durch die Ausstellung;* Wien, 1894.

PGiss. = *Griechische Papyri im Museum des Oberhessischen Geschichtsvereins zu Giessen.* Vol. I; Leipzig-Berlin, 1910–1912.

PGrenf. II = B. P. Grenfell and A. S. Hunt, *New Classical Fragments and other Greek and Latin Papyri;* Oxford, 1897.

PLips. = L. Mitteis, *Griechische Urkunden der Papyrussammlung zu Leipzig;* Leipzig, 1906.

PLond. IV = *Greek Papyri in the British Museum: Catalogue with Texts.* Vol. IV, *The Aphrodito Papyri;* London, 1910.

PSchott-Reinhardt = *Veröffentlichungen aus der Heidelberger Papyrus-Sammlung.* Vol. III, *Papyri Schott-Reinhardt;* Heidelberg, 1906.

PStud. X = C. Wessely, *Studien zur Palaeographie und Papyruskunde.* Vol. X, *Griechische Texte zur Topographie Ägyptens;* Leipzig, 1910.

SB = F. Preisigke, *Sammelbuch Griechischer Urkunden aus Ägypten;* Strassburg, 1915 (Vol. I).

TAPA = *Transactions of the American Philological Association.*

UKF = Wessely, *Studien,* vols. III + VIII, *Griechische Papyrusurkunden kleineren Formats;* Leipzig, 1904–1908.

WChrest. = L. Mitteis und U. Wilcken, *Grundzüge und Chrestomathie der Papyruskunde.* Vol. I, *Historischer Teil.*

A very useful review of the Aphrodito Papyri, from the standpoint of the Arabist, is given by Nabia Abbott, *The Ḳurrah Papyri from Aphrodito in the Oriental Institute* (Oriental Institute of the University of Chicago: Studies in Ancient Oriental Civilization, No. 15; Chicago, 1938).

[2] ἐτάξαμεν διὰ τῆς διοικήσεως σου δισχιλ[ίας] ἀρτάβας σίτου καὶ τὰ τούτων ἐντάγια ποι[ήσαντες] τοῖς τῶν χωρίων ἐπέμψαμέν σοι.

[3] φ[ο]ι[νικ]ο̣δ̣ό̣κια καὶ ἕτερ[α] εἴδη ἐτάξαμεν .... καὶ τὰ τούτων ἐντ[ά]για ποιήσαντες τοῖς τῶν χω(ρίων) ἐπέμψαμέν σοι.

of iron for making nails for the frigates . . . and we have subjoined the specification of the same iron to the present letter. . . . Receive such iron and apportion it among the localities in accordance with the tenour of our *entagia*, which have been sent to you."[4] In 1354, "let it not become known to us that there has been collected from the people of your administrative district any money composition for maintenance whatever at a lower rate than the valuation which we have inserted in our *entagia*."[5]

It appears clearly from these quotations that an *entagion*, in the official terminology of this period, was a demand-note for taxes or services. This inference is confirmed by the fortunate survival, both among the Aphrodito papyri and elsewhere (see *Archiv für Papyrusforschung*, V: 189–191, and L. Casson, TAPA, **69**: 275[4], 1938), of some actual examples of the class. It is true that these documents do not themselves contain the word *entagion*, but their contents conform so exactly with what the passages quoted above lead us to expect that there can be no doubt as to their nature. A translation of two of them will sufficiently exemplify their formulae and character:

PSchott-Reinhardt, p. 111, g:

In the name of God. Ḳurrah b. Sharīk, Governor, to you the people of the monastery of St. Mary in Kômê Aphroditô. Your share of the public taxes of the 6th indiction, which by the Arab reckoning is year 88, is 98 = ninety-eight *solidi*, and for embola 88 = eighty-eight artabas of wheat, only. Written in the month of Thoth, 8th indiction. Total 98 *solidi*, 88 artabas of wheat.[6]

PLond. IV, 1408:

In the name of God. Ḳurrah b. Sharīk, Governor, to you the people of the Five Fields in Kômê Aphroditô. Receive from your pagarch 50 = fifty *litrae* of unrefined lump iron from the government store and make in into 33⅓ = thirty-three and a third *litrae* of nails of refined iron, which you are to deliver to ʿAbd al-Aʿla b. Abī Ḥakīm for the frigates and sloops for the present 8th indiction and the expedition of the 9th indiction; and if you give wages [that is, instead of doing the work yourselves] pay for 50 *litrae* of lump iron for refining 1⅓ = one and a third *solidus* only. Written the 6th Thoth, 8th indiction. Total 50 *litrae* of unrefined iron, to be refined to 33⅓ *litrae;* 1⅓ *solidus*.[7]

The evidence contained in the archive of Basil, the pagarch of Aphrodito, enables us to determine with some exactness the procedure followed in the assessment and collection of taxes in Arab Egypt. Registers of all the inhabitants and of their holdings in landed property were prepared in every pagarchy, taken to the capital, Fusṭāṭ, and deposited in the Dīvān, where they formed the basis of assessment. The total amount of tribute, that is, the sum total of the taxes required from Egypt, was divided in accordance with this information between all the pagarchies, and each pagarchy's share was further subdivided, again at headquarters, among all the villages or other units within it. Thus was established the permanent quota or ἐπιζητούμενα of both ordinary (or public) and extraordinary taxes. As occasion arose requisitions were made for payment of such proportion of the total as was required, and also for services like the making of nails in the document quoted and the supply of provisions, manufactured articles, labourers, craftsmen, and sailors. Every such requisition was communicated in a letter from the Governor to the pagarch, or rather in two letters, one in Arabic, one in Greek. The Arabic letters, written in bold Kufic characters across the fibres of the papyrus, bore the Muhammedan formulae and were dated by the Hegira. For example, PSchott-Reinhardt I begins: "In the name of God the Merciful, the Compassionate. From Ḳurrah b. Sharīk to Basil, administrator of Ashḳūh. I praise God,

[4] ἀνιστειλαμέ[ν σο]ι [ ] λόγῳ ποιήσεως πησσομένων τῶν καράβων σιδήρου κεντηνάρια τέσσαρα .... κ[αὶ] ἰδοὺ τὴ[ν] διαίρεσιν τοῦ αὐτοῦ σιδήρου ὑπετάξαμέν [σ]οι ἐν τῇ παρούσῃ ἐπιστολῇ .... παράλαβε τὸ τοιοῦτο σίδηρον καὶ διάστειλον αὐτὸ διὰ τῶν χωρίων πρὸς τὴν δύναμιν τῶν σταλέντων σοι ἡμετέρων ἐνταγίων. I have ventured to render *karaboi* by "frigates."

[5] μὴ γνώσθῃ ἡμῖν ὡς ἠνύσθη ἐκ τῶν τῆς διοικήσεως σου ἀπαργυρισμὸς δαπάνης τὸ καθόλου κάτωθεν ἧς ἐνεθήκαμεν ὡς λέλεκται ἀποτιμήσεω[ς] ἐν τοῖς ἡμετέροις ἐνταγίοις.

[6] Ἐν ὀνόματι τοῦ θεοῦ. Κορρα υἱὸ(ς) Σζεριχ σύμβο(υ)λο(ς) ὑμῖν τοῖ(ς) ἀπὸ μοναστη(ρίου) ἁγία(ς) Μαρ[ίας κώ]μ[ης Ἀφ]ρ[οδ]ι-[τώ. Ἐ]λ̣[αχεν ὑ]μ[ῖν (ὑπὲρ) δημοσίων] ἰνδ(ικτίον)ο(ς) ϛ κ(α)τὰ Ἄρα(βας) ἔτους πη ἀρ(ί)θ(μια) ν(ομίσματα) ϛιη ἐνενήκοντα ὀκτὼ [(καὶ)] (ὑπὲρ) ἐμβολῆς σί(του) ἀρτ(άβας) πη ὀγδοήκοντα ὀκτὼ μ(όνα). Ἐγρά(φη) μη(νὸς) Θὼ(θ) ἰνδ(ικτίον)ο(ς) ὀγδόης. Γί-(νονται) νο(μίσματα) ϛιη, σί(του) ἀρτ(άβαι) πη.

[7] Ἐν ὀνόματι τοῦ θεοῦ. Κορρα υἱὸ(ς) Σζεριχ σύμβουλος ὑμῖν τοῖς ἀπὸ (Πέντε) Πεδιάδων κώμη(ς) Ἀφροδιτώ. Παραλάβετε ἐκ τ(οῦ) ὑμε(τέρου) παγάρχ(ου) σιδήρου μαζίου τοῦ δημοσίου ῥυπαρ[οῦ] (λίτρας) ν πεντήκοντα (καὶ) ποιήσατε καθ(αροῦ) (λίτρας) λγ ϛ τριάκοντα τρεῖς τρίτον πησσομένων (καὶ) ταῦτα παραδώσατε Ἀβδελαλε υἱο (*sic*) Ἀβι Ἀχιμ Λ̣[όγῳ] ϗ[αρ(άβων) (καὶ)] ἀκα(τίων) ἐπὶ τ(ῆς) παρού(σης) ἰ(ν)δ(ικτίονος) η κούρσου δὲ ἰ(ν)δ(ικτίονος) θ, (καὶ) ἐὰν δώσητ(ε) μισθῷ(ν) (*sic*) παρ[ασχ(ετε)] (ὑπὲρ) (λιτρῶν) ϛι[δ]ἠρ[ου] μ[α]ξ(ίου) ν λό[γ(ῳ)] κ(α)θ-(ἀρσεως) ἀρ(ίθμιον) ρ[όμισμα)] α ϛ ἐν τρίτον μό(νον). Ἐγρά-(φη) μ(ηνὸς) Θὼ(θ) ϛ ἰνδ(ικτίον)ο(ς) ὀγδόης. Γί(νονται) σιδ-(ήρου) ῥυπα(ροῦ) (λίτραι) ν εἰ(ς) κάθ(αρσιν) (λίτραι) λγ ϛ, νό(μισμα) α ϛ.

besides whom there is no god. Next," and ends "This was written by Garīr in the month Rabī' I in the year ninety-one."[8] The Greek letters, written by Christian clerks in the Dīvān, have no distinctively Muhammedan formulae and are dated merely by the indiction. Thus, in PLond. IV, 1353, "In the name of God. Ḳurrah b. Sharīk, Governor, to Basil, administrator of Kômê Aphroditô. We give thanks to God; and next," and, at the end, "Written Mecheir 5th, 8th indiction."[9] They too are written across the fibres, in a free, flowing cursive hand, with long up- and down-strokes, much linking of letters, and (apart from the dating clause) practically no abbreviations. Many have at the top minutes in either Greek or Arabic, or in both. The Greek minutes, as well as the schedules found at the foot of several, are written in a quite different hand from the letters themselves, small, compressed and upright, of the type known in vellum manuscripts as minuscules, and heavily abbreviated. At the foot of each letter was a seal (*Untersiegelung*), and the whole, when completed, was rolled, tied up (perhaps with fibres of papyrus), and then no doubt sealed (*Versiegelung*). The address, in the form (e.g.) *κορρα νι° σζεριχ συμβουλος βασιλειω διοικ⁻/ κωμ" αφρο^{δ}*, was then added, the Governor's name on one side of the seal, that of the recipient on the other. The dockets (in minuscule script and with many abbreviations) which are often found on the verso beneath the address but the other way up were presumably written by a clerk in the pagarch's office, in order to facilitate ready identification of a letter in the files.

With every couple of letters concerning any requisition, whether of ordinary or extraordinary taxes, of money, goods, or services, went the requisite number of *entagia*, one to each of the places within the pagarchy from which a contribution was required. These *entagia* were markedly different in form from the letters to the pagarch, though in them too the writing was across the fibres. Arabic and Greek texts were written not in two separate rolls but on a single sheet of papyrus, the Arabic always coming first. Verbally Arabic and Greek were closely similar; the Greek portions differed from the Greek letters to the pagarch not only in some of the formulae but also in the hand, which was of the minuscule type employed in the dockets to the letters, and which abounded in abbreviations. The *entagia*, moreover, were addressed not to an individual official (who would properly have been the *lashane* or village headman) but to the inhabitants as a whole (or, less probably, to the body of officials).

There was a definite reason for this difference of hand; I have elsewhere[10] suggested that the evidence then available (and I know of no counter-evidence published since) indicated that letters addressed to a community, which perhaps were meant to be publicly exhibited, were in minuscules.

At the foot of each *entagion* the amount of the requisition was summarily restated, and this summary was then rolled up and sealed, in a manner recalling the "double deed" of Ptolemaic times, where however it was the upper text which took the form of a summary and which was rolled up and sealed. A collection of *entagia* at Strasbourg, published by Becker as an *Anhang* to his PSchott-Reinhardt, was, when acquired, according to Becker, "eng zusammengepresst und wirkten von aussen als einheitliche Rolle." This was probably the form in which *entagia* were originally sent to the pagarch; as these particular ones were found rolled up together and still had the seals closing the *scriptura interior* or recapitulation at the foot, it is probable that the roll had never been opened and the single *entagia* distributed to the places concerned; but the *entagia* may just possibly have been returned from there to the pagarch (see below) and reunited in his office.

It is natural to enquire whether this system was introduced by the Arabs or was taken over by them, with the necessary modifications, from the Byzantine Empire. The latter is *a priori* the more likely. We know that the Arabs, a people unused to the management of an empire, adopted much of the administrative machinery which they found in the provinces acquired by them; we also know that they showed considerable skill in adapting this machinery to suit their own needs or, as in the rather excessive centralization introduced by them in Egypt, to avoid defects which had contributed to the Byzantine collapse. It is reasonable to suppose

[8] I translate from Becker's German translation, merely changing Ašfūh to Ashḳūh (Becker, after learning the provenance of the papyri, recognized that the letter was *ḳ*, not *f*).

[9] *'Εν ὀνόματι τοῦ θεοῦ. Κορρα βε(ν) [Σ]ζε[ριχ σύμ]βο[υλ]ος Βασιλείῳ διοικητῇ κώμης 'Αφροδιτώ. Εὐχαριστοῦμε[ν] τῷ θεῷ, καὶ μετὰ ταῦτα. . . . 'Εγρ(άφη) μη(νὸς) Μ(ε)χ(είρ) ε ἰνδ(ικτίονος) η.*

[10] JEA., xii (1926), 266.

that their *entagion* had a Byzantine forerunner; and although, as already said, the word in Byzantine texts most often means "receipt" there are instances of a use similar to that of Arab times. The most striking early example is in PGiss. 54 (WChrest. 420), a letter of the fourth–fifth century to a man nominated for the post of διαδότης. After urging his correspondent to hasten to the sphere of his duties, the writer adds: καὶ ἀπέστειλα ὑμῖν τὰ ἐντάγια τῶν ἀννωνῶν [τῆ]ς νέας ἰνδικτίονος, ἵνα λάβῃς τούτων τὰς ἀπ̣[ο]χάς; i.e. "I have sent you the *entagia* for the *annonae* of the new indiction in order that you may receive the receipts for them." There is no doubt that here *entagion* means a demand note; and an earlier sentence in the letter shows how the word originated. The reason given for haste is: πολλοὶ γὰρ σῖτον καὶ κριθὰς ἐνετάγησαν εἰς τὰ μέρη ἐκεῖνα. The sense assigned by Preisigke in his *Wörterbuch* to the verb ἐντάσσω in this passage is "ansammeln, aufhäufen," but surely the true meaning of the passage is "corn and barley have been requisitioned from many," ἐντάσσω meaning in the active *to requisition, to order from*, in the passive *to have a requisition served on one*. It was from ἐντάσσω in this sense that the word *entagion* was coined to express the document which communicated the order.

Another instance is SB 5273, a document of warranty dated in A.D. 487, in which it is guaranteed that a collector of public corn shall deliver all the corn he has collected κατὰ τὰ παρ' αὐτ[οῦ] παρεχόμενα προγρ̣άφια ἢ καὶ ἐντάγια, "in accordance with the warrants or *entagia* produced by him."

This sense of *entagion* was however exceptional in the Byzantine period. Even as early as 371 we find, in PLips. 58, 13 and 18, that the word is used in a context which makes the simple translation "demand note" impossible. Mitteis renders "die (quittierten) Aufträge," and in his introduction remarks "Demnach ist ἐντάγιον hier in dem prägnanten Sinn von einer *quittierten* Einhebungsanweisung zu verstehen." His view appears to be that the delivery of the specified amount was noted on the demand note, which thus became a receipt, and that in this way the word came to mean "receipt."

Entagion was now an ambiguous word, and it is not surprising, on occasion, to find an alternative term employed. In a document, probably of the fifth century, edited by Mlle. Rouillard in the *Mélanges Desrousseaux*, πρόσταγμα seems to be used instead: "I have received from your worship for the *prostagma* of the dykes of the 15th indiction another nine pieces of gold . . . and I am prepared to pay the said other nine pieces of gold to the messenger who brings me the said *prostagma*."[11] Here *prostagma* seems to have a sense very similar to that of *entagion*.

It is clear from what I have said that in Byzantine Egypt also demand notes of some description were employed in the process of tax collection, and these, at least in the earlier period, bore the name *entagion*. It is less easy to answer the question whether in form they were similar to the Arab *entagion*. Obviously they were not bilingual, and the differentiation of the Byzantine cursive hand into the current type seen in letters and the minuscule of *entagia* was probably not perceptible till towards the end of the period. The formulae, however, may quite well have served as a model to the clerks of the Arab Dīvān. The difficulty of settling this question lies in the fact that such documents were normally dated only by the indiction, except at Oxyrhynchus, where the so-called Oxyrhynchite eras were sometimes added. Anybody who has worked at papyri of the later Byzantine period will know how hazardous it is, on grounds of script alone, to decide whether a document was written before or after the Arab conquest. Moreover, in the case of several documents which are either described as *entagia* or resemble others so called it is uncertain, owing either to mutilation or to abbreviation, whether they are to be interpreted as receipts or orders.

It seems to me probable that the Arab *entagion*, as used in the collection of taxes, was derived ultimately from the orders for payment of which many examples exist and which, from the fifth century onwards, show a fairly uniform structure. These are usually from private individuals, corresponding in some degree with the modern cheque, but official examples occur, and one of these, certainly of the Byzantine age, is actually called an *entagion*. This is UKF 1025, which is assigned by the editor to the fifth century. It reads:

From Sarapion, municipal accountant of Hermopolis (?), to . . ., collector. Pay to Banos, baker, two artabas of wheat = wheat, 2 artabas. Pharmouthi . . . Flavius Sarapion, senator(?): I

[11] Ἔχω τῆ[ς σ]ῆς θαυμασιώτητος ὑπὲρ το[ῦ] προ[στ]άγματος τῶν χομάτων τ[ῆ]ς πέμπτη[ς] καὶ [δεκ]άτης ἰνδικτίωνος ἕτερα χρύσινα ἐννηὰ .... καὶ ἑτοίμως ἔχω τὰ αὐτὰ ἕτερ[α] ἐννηὰ χ[ρύσινα κ]αταβάλλε[ι]ν τῷ προσφέροντί μοι τὸ αὐ[τὸ] πρόσταγμ[α].

agree to the *entagion* for the two artabas of wheat as aforesaid.[12]

Here an *entagion* is an official order for payment, not indeed by a taxpayer to a collector but by a collector to an individual, probably a baker working for the municipal bread supply; but it is easily conceivable that the form, with the name, might develop into the type of document found in Basil's archive at Aphrodito, and the development may well have been completed before the Arab conquest. Unfortunately I have found no example from the late Byzantine period. I may however mention, in concluding this section of my article, a possible reference to *entagia* as demands for taxes in the Byzantine period. This is UKF 294, a receipt dated by Wessely in the seventh century, given to a deacon for six *solidi* paid by him (*ὑπὲρ*) *τ(ῆς) διαγρ(αφῆς) τῶν προσόδων πέμπτης ἰνδ(ικτίονος)*, which concludes with the words *ἄκυρα δὲ (καὶ) ἀνίσχυρα τὰ ἐντ[άγ]ια (ὑπὲρ) τ(ῆς) αὐτ(ῆς) ε ἰνδ(ικ.)*, that is to say, the payment of the money cancels the validity of the demand notes. Since however this document is placed in the seventh century, it may date from after the Arab conquest.

The subject of the *entagion* has recently acquired a new interest owing to the discovery of several examples of the class outside Egypt. At ʿAuja Ḥafīr in Southern Palestine the Colt Expedition made, in 1936, two separate discoveries of papyri, one archive dating from the sixth century, another from the early Arab period. In this second find were included seven *entagia*, dating from the fifty-fourth, fifty-fifth, fifty-sixth, and fifty-seventh years of the Hegira and showing a remarkably close resemblance in formulae and arrangement to the Aphrodito examples of thirty years later. Like them, they are bilingual, the Arabic coming always first, and the Greek written in minuscules of a type indistinguishable from the hand as written in Egypt, and abounding with abbreviations. There are naturally some differences in detail, but the general resemblance is close.

The divergences from Egyptian practice seen in these Palestinian *entagia* (the formulae of which are remarkably constant) are as follows: The official making the requisition does not give his title. In contradistinction to the Egyptian examples, in which we find a variety of phrases, *παράσχετε, πέμψατε καὶ παραδώσατε, ἔλαχεν ὑμῖν*, in the Palestinian documents the actual order is invariably expressed by the words *παράσχετε ταχέως*. The requisitions are in all the examples found (but this is doubtless accidental) for wine and oil, always in equal quantities, and (with one exception, where the omission may be accidental) for a specified but varying period. The months concerned are always indicated by their Arabic names. In the dating clause, unlike the Egyptian examples, which mention the indiction only, both indiction and year of the Hegira are stated; the months are the Roman months, and, again in contradistinction to the Egyptian practice, the day of the month is not mentioned. Furthermore, the clerk who wrote the *entagion* is always named in the ʿAuja examples, never in those from Egypt, and in the former the collector (always, except apparently in 6, an Arab) is named, whereas this was never done in Egypt, presumably because the money or goods requisitioned went not directly to headquarters but to the headmen of the *χωρία*, then to the pagarch, and only after collection in his office would the total quota of the pagarchy be conveyed to Fusṭāṭ. At ʿAuja the payments were apparently collected by the messenger who brought the *entagion;* this at least is a reasonable inference. Finally, the recapitulation of the amount at the foot of the document is in the ʿAuja examples in both Arabic and Greek, in the Egyptian ones in Greek only.

These minor differences do not seriously detract from the remarkable similarity between Egyptian and Palestinian *entagia*. This similarity may be accounted for by the supposition either that a more or less uniform pattern in the demand note had been developed in the Byzantine Empire and was taken over by the Arabs in every province conquered by them or that, finding in use, whether in Egypt or in Palestine or elsewhere, a form of demand note which they judged convenient, they adopted it as a pattern for their own procedure elsewhere. The first is *a priori* the more likely; but it may be, since no Byzantine *entagia* of quite the same kind as the Greek portions of those used by the Arabs have yet come to light in Egypt, that the type was first evolved in Palestine and from there introduced by the Arabs into other provinces.

[12] *Π(αρὰ) Σαραπίωνος πολιτικοῦ λογισ[τ(οῦ)] Ἐρ(μουπόλεως?) [. . . ., παρα]λήμπτη. Παράσχου Βάνῳ ἄρτοκ(όπῳ) σίτου ἀρτάβας δύο, σί(του) ἀρ(τάβας) β. Φαρμοῦθι [.] Φλ(αούιος) Σαραπίων πολιτ(ευόμενος?) συμφ(ωνεῖ) τὸ ἐντ[άγιον] τῶν δύο ἀρταβῶν [τοῦ] σίτ[ο]υ ὡς πρόκ(ειται).*

UKF. 1065 (5th–6th cent.) is a very similar order from a *comes* to a *pronoëtes*, described in the docket on the verso, though not in the main text, as an *entagion*.

From this uniformity in the matter of the *entagia* we may reasonably argue to an equal agreement in the general procedure. In other words it is a fair inference that letters, like those from Aphrodito, in Arabic and in Greek, were sent to whatever local official in Palestine corresponded to the Egyptian pagarch, and were accompanied, as in Egypt, by the necessary *entagia*. It is not an objection to this hypothesis that no such letters have been found. Though the *entagia* were, in Egypt, sent to the pagarch, not directly to the places concerned within the pagarchy (they were always *addressed* to them), it was the pagarch's duty to transmit them to their ultimate destination; and at Kôm Ishgau, where the archive of the pagarchs was discovered, the *entagia* found were far fewer than the letters. It might indeed be expected that only those referring to Aphrodito itself would have been stored there, and this was probably the rule, the apparent exceptions being due to accident. The *entagia* preserved separately are all to Kômê Aphroditô itself or to its subdivisions, not to the independent ἐποίκια,[13] viz.: PLond. IV: 1407, 1410, 1411 to κώμη Ἀφροδιτώ, PLond. IV: 1408 to Πέντε Πεδιάδες, PSchott-Reinhardt 5 to [...] Πεδιάδες, the sole exception being PSchott-Reinhardt 6, to μοναστήριον Βαρβαρίου (*sic;* usually Βαρβάρου). Apart from this last the apparent exceptions are all among the Strasbourg texts, which were perhaps never delivered to the χωρία, since, as already explained, they were found still rolled up in a bundle, with seals unbroken. PSchott-Reinhardt 6 seems however to be a genuine exception; perhaps this one was for some unexplained reason returned to headquarters. Now in Egyptian examples the position of a χωρίον is always stated, e.g.: ἐποικίου Πακαύνεως κώμης Ἀφροδιτώ, ἐποικ(ίου) Βουβαλίτου Περὶ Πόλ(ιν) πόλεως Ἀντινόου (*Arch. f. Pap.*, v, 189f.). The Ἄuja *entagia* offer an exact analogy: Νεστάνων κλίματος Ἐλούσης χώρας Γάζης. It appears then that Ἄuja is Nestana and that Nestana was a subdivision of Elusa, to which, as the headquarters of the local administration, we may suppose the covering letters to have been sent (unless indeed they were delivered at Gaza), only the *entagia* intended for Nestana going to the latter. The presence among them of 5 is however inexplicable; since the place concerned was in the κλίμα of Sycomaza it cannot be regarded as a subdivision of Nestana. Perhaps it arrived there by mere accident.

Before discussing the special problems of these Ἄuja *entagia* it seems worth while to raise the question who issued the demand notes to individual taxpayers as opposed to localities. The papyri from Egypt provide some material for answering this question, and we may perhaps venture to apply our conclusions, at least tentatively, to Palestine also. One would have expected *a priori* that the quotas of the pagarchies would have been notified to the pagarch by the authorities at Fusṭāṭ, that those of the χωρία would have been notified by the pagarch to the *lashane*, and that the *lashane* would in his turn notify the individual taxpayer. We have seen however that the Dīvān at Fusṭāṭ fixed the quotas not merely of the pagarchies but of the χωρία within them; and it appears clearly from surviving *entagia* that it was not the village *lashane* but the administrator of the pagarchy who notified the individual taxpayers. Usually, it is true, the title of the official issuing these individual *entagia* is not given, but in every case but one (UKF 1180, Παῦλος υἱ(ὸς) [....]) he is an Arab, and it is not conceivable that at this period (seventh–eighth century) an Arab should have been a mere village *lashane*. The rule is clearly established by UKF 260, Ἰαειε υἱ(ὸς) Ἠλαλ ἐπικ(είμενος) παγαρχ(ίας) Ἀρσιν[ο]ίτου. Here we have the pagarch of the Arsinoite nome, which was big and important enough, unlike Kômê Aphroditô, to call for an Arab in charge. As the same name occurs, without the title, in UKF 1199, 1200, which refer to a place in the Arsinoite nome, they too are shown to have been issued by the pagarch.[14] Hence Ῥασζιδ υἱ(ὸς) Χαλεδ, who occurs in UKF 1083, 1195, PStud. X: 197, was presumably pagarch of Heracleopolis, to which place these *entagia* refer. UKF 1195 fixes his date as *circa* A.D. 722; thus Paul son of . . ., who addresses an *entagion* to an inhabitant of Heracleopolis in UKF 1180, was presumably an earlier pagarch (Wessely dates the document "s. VII"), since the appointment of Arabs to local governorships is likely to have increased in frequency with the lapse of time. In UKF 1183, dated by Wesseley "s. VII–VIII," also from Heracleopolis, the official is Ἄμβρος υ[ἱ](ὸς) Οὐβηειδ. In UKF 1184 ("s. VII–VIII") occurs Νεγιδ υἱὸ(ς) [M]ουσλη(μ); his

[13] For the subdivisions of the village and pagarchy of Aphrodito see PLond. IV: xiv.

[14] Yaḥyā b. Hilāl wrote the letter (dated A.D. 745) PERF 608.

title is not named, and the χωρίον Ἀπαμ( ) from which the taxpayer comes does not seem to be known, but the word παγαρχ(ίας) following the place-name may suggest that the *entagion* was issued by the pagarch. Lastly, in PGrenf. II: 105, 106 (republished by L. Casson, TAPA **69**: 289), two *entagia* of the year A.D. 719, both relating to a place in the Heracleopolite nome, Ζουβεειρ νί(ὸς) Ζιαδα may be confidently recognized as a pagarch earlier than Rashīd but later than Paul.[15]

These individual *entagia* differ from those addressed to communities in lacking the Arabic version, which would obviously have been purposeless here. It may be noted further that they are regularly addressed ὑμῖν, not σοι in the prescript, though the singular may occur later on. This fact is perhaps explained, and the apparently excessive centralization of the whole machinery elucidated, by UKF 1199, 1200. The first consists of four, the second of two (and perhaps a third) skeleton *entagia*, in which, though the names of the pagarch (Yaḥyā b. Hilāl) and the place (Βουβάστου) are given, that of the taxpayer and the amount of his tax quota are omitted. The inference is clear: all that the pagarch sent out (unless indeed the *entagia* were actually written locally, in his name) was a bundle of blank forms, which the local officials filled in as required. This would obviate the cumbrous procedure of sending to the pagarch's office an assessment list for every χωρίον, the writing there of *entagia* for all the taxpayers, and the despatch of these to the *lashane*. It does not appear however whether in the completed *entagia* the details omitted in UKF 1199, 1200 are later insertions. These minuscule hands show so great uniformity of character that it is often very difficult to settle such points, and in the absence of any certainty in this matter the above inference can be generalized only with reserve.

This however is a digression, and I must return to the *entagia* intended for localities. The seven examples from ʿAuja here edited are all, with one exception, orders for wheat and oil only; and it is worth noting that in every case the number of *modii* of wheat corresponds exactly with the number of *sextarii* of oil. The supplies demanded are described as for a stated period, which however varies: the *quadrimenstruum* seen in Byzantine orders for military supplies is not observed here. In five cases the period is two months (but in (4) the number is doubtful), which was perhaps the normal period; in one (1) it is five; and in one (7) no period is specified, nor is any month named. This is perhaps owing to inadvertence, or the demand may be for an extraordinary levy. The amounts requisitioned bear no relation to the period covered: thus, in (1), for five months, the figure is 70 *modii*, 70 *sextarii*, but in (2), for only two months, it is 96, and in 3, also for two months, it is 310. We are not dealing therefore, with a fixed and recurring monthly quota but with instalments, demanded as required, of a total annual amount.

The exception referred to above is (5). Here the requisition, dated in the fourth indiction, is for 279 *modii* of wheat, 279 *sextarii* of oil, and $18\frac{2}{3}$ *solidi*, the price of the same quantities of wheat and oil. A tentative explanation is suggested in the note *ad loc.*, but it is not by any means assured, and others are conceivable: e.g., the cash demand may be a penalty for nonpayment of the original requisition, or there may have been a mistake in drafting, the cash demand being for arrears, the demand in kind for the two months named; but neither of these suggestions is entirely convincing.

In the Egyptian *entagia*, both communal and individual, the object of the requisition is regularly stated, but this is not done in any of the ʿAuja examples, which merely specify the amount required. Possibly the reason is that these requisitions were for some regularly recurring purpose, e.g., the *rizḳ*, or allowance in kind, of the Muslims. In the Greek Aphrodito papyri this appears as ῥουζικόν, the allowance in money being ῥογά. The requisitions at ʿAuja are always in kind, except that in the case of (5), mentioned above, there is an apparent instance of *adaeratio*.

As already said, in both the ʿAuja and the Aphrodito *entagia* the amount of the requisition is repeated summarily at the foot, but with one difference: in the ʿAuja examples the recapitulation is in both Arabic and Greek (normally in that order, as in the body of the document, but in 1 and 7 the order is reversed), whereas in those from Aphrodito it is in Greek only. In view of the later date of the latter this is a little strange:

[15] Casson, *op. cit.*: 290f., makes it clear that PERF. 586 is not, as taken by Grohmann, an *entagion* but a tax-receipt. Note that it is addressed not to an individual but to τοῖς ἀπὸ a place. Compare UKF. 1198, where we may be sure that κα[τεβλήθησαν] was rightly restored by Wessely (not an imperative). It is perhaps justifiable to conclude that the communal quota of the χωρία was receipted by the pagarch but that the receipts to individuals were issued by the local tax collectors.

the evolution was obviously from Greek to Arabic as the official language of administration, and we should expect a bilingual recapitulation (preceding an eventual dropping of the Greek element) in the later rather than the earlier *entagia*. Perhaps Egyptian practice was more conservative than Palestinian.

When the recapitulation had been written the portion of the papyrus containing it was folded or rolled up and closed by means of a mud seal. This, even where it has disappeared, has left a trace; and I have in all cases indicated the point at which the seal covering the recapitulation was visible below the main text.

What was the purpose of this sealed recapitulation? It cannot have been a mere survival of the old "double deed," with *scriptura interior* and *scriptura exterior*, though in fact the former was in time reduced to a mere summary. The purpose was however presumably the same: to guard against a fraudulent alteration of the requisition. A dishonest official might, in the interest of the taxpayers and in return for a bribe from them, wash out the original amounts and substitute smaller quantities. The sealed recapitulation, duplicating the figures, had, we may infer, to be left untouched till the goods were delivered to the messenger, who would in case of doubt break the seal and check the quantities with the *scriptura interior*. That he did not invariably do so is shown by the fact that in four of these *entagia* (1, 2, 3, 7) the seals had never been broken.

Below are published the Greek portions of the seven 'Auja entagia. Owing to my interest in this documentary form, acquired during my work at the Aphrodito papyri, the directors of the Colt Expedition kindly left them with me, to edit for the projected volume. I had finished so much of my part of the task as could be completed without the commentary on the Arabic portions, which were being edited by Prof. L. A. Mayer of Jerusalem, and without such further evidence as might be contained in the remaining documents of the find, when the war broke out. The papyri, preserved in the strong room of the Department of Manuscripts, British Museum, have fortunately escaped the perils of the air attacks on London, but I had no opportunity to do further work on them till, early in 1944, Professor Casper J. Kraemer, Jr., wrote to me asking me, as it is impossible to proceed with the 'Auja volume till after the war, to publish the Greek portions of the *entagia* separately. I desire here to acknowledge my gratitude to him and his colleagues for their kindness, as well as for some useful suggestions pencilled on the typescript copy of my provisional transcripts. I must also thank Mr. Fulton, Keeper of the Department of Oriental Printed Books and Manuscripts at the British Museum, for his assistance in the transliteration of Arabic names and words.

The *entagia* being so constant in their form, I have not thought it necessary to translate more than the first and one other (5), which shows somewhat different formulae. I have confined the commentary to points arising from the texts published, and have not attempted to prejudge the problems raised by the 'Auja find as a whole or to anticipate information more properly reserved for the complete publication. I have numbered the Greek lines separately, without reference to the Arabic.

All the *entagia* are written across the fibres, i.e. across the width, not in lines parallel to the length, of the roll from which the sheets of papyrus were cut. The evidence of nos. 1, 5 (l. 12), 6, 7, where the Arabic is continued on to a line of the Greek text, shows that the latter was written first. The abbreviations and symbols used are those familiar in the texts from Egypt. It is to be noted that plurals, as there, are indicated by a doubling of the consonant, both in nouns ($\mu^{\eta}\mu^{\eta}$) and verbs ($\pi^{\chi}\pi^{\chi}$).

When I had nearly finished my preliminary work on the *entagia* an eighth document, regarded as one of the series, reached me from New York; and I have been asked to publish this also. It proves on examination to be not an *entagion* at all but an official letter; but I thought it best to publish it as an appendix to the others, though it is too imperfect to yield anything of much interest.

1. November, A.D. 674.

32.2 cm. by 18.1 cm. Damaged on the right.

Arabic, 9 lines.

Ἐν ὀνόμ(ατι) τοῦ θεοῦ· Arabic.
Ἀλλααρεθ β(εν) Ἀβδ τοῖ(ς) ἀπὸ Νεστάνων κλήμα-(τος) Ἐλούσης χώρ[α(ς)]
Γ[ά]ζης. Π(αράσ)χ(ετε) τ(α)χ(έως) Ἀδιλ β(εν) Χαλεδ τῶ(ν) Β(ανι) Σααδ β(εν) Μαλεχ (ὑπὲρ) μη(νῶν) ε Δουλκ(α)δ(α)
(καὶ) Ἀλμου(αρραμ) (καὶ) Σαφ(αρ) (καὶ) Σααραειν Ῥαβη σ̣ί(του) μ(ο)δ(ίους) ἑβδομήκοντα, ἐλ[αίο(υ) (ξέστας)]

ἐβδομήκοντα. Ἐγρά(φη) μ(ηνὶ) Ν[ο]εμβρ(ί)ῳ ἰνδ-(ικτίον)ο(ς) γ, κ(α)τ' Ἄραβ(ας) [ἔτους νδ],
χειρὶ Ἀλεξάνδρου Ἀμμωνίου. Ὅ(λου)· σίτ(ου) μ(ό)δ(ιοι) ο, ἐλα[ιό(υ) (ξέσται) ο.]

[Seal.]

(2nd hand?) Ὅ(λου)· [σ]ί(του) μ[(ό)δ(ιοι)] ο, ἐλαί(ου) (ξέσται) ο. ////

Arabic, 1 line.

2. 1. κλίματος. 5. ἰνδ°/.

In the name of God: Al-Ḥārith b. 'Abd to the people of Nestana in the region of Elusa, province of Gaza. Pay quickly to 'Adīl b. Khālid of the Bani Sa'd b. Malik for the 5 months Dhu'l-ḳa'dah and Al-Muḥarram and Ṣafar and the two Rabī's seventy *modii* of wheat, seventy *sextarii* of oil. Written in the month of November of the 3rd indiction, year 54 according to the Arabs, by the hand of Alexander son of Ammonius. Total: 70 *modii* of wheat, 70 *sextarii* of oil.

6. The recapitulation at the end seems to be in the same hand as the rest. That in l. 7 is probably in a different hand. That it should there precede the Arabic is contrary to custom.

2. August, A.D. 675.

33.3 cm. by 17 cm. Damaged in places on the right.

Arabic, 9 lines.

Ἐν ὀνόμ(α)τ(ι) τοῦ θεοῦ· Ἀλλααρεθ β(εν) Ἀβδ τοῖ(ς)
ἀπὸ
Νεστάνων κλίμ(ατος) Ἐλούση(ς) χώρα(ς) Γάζης.
Π(αράσ)χ(ετε) τ(α)χ(έως)[
β(εν) Ζαιδ τῶ(ν) Β(ανι) Σααδ β(εν) Μαλεχ (ὑπὲρ)
μη(νῶν) β Ῥαγαβ (καὶ) Σ[ζαβαν]
ὑ(πὲρ) καρπ(ῶν) ἰνδ(ικτίον)ο(ς) δ̄ σίτ(ου) μ(οδίους)
ἐνενήκοντα ἕξ, ἐλ[αίο(υ) ξ(έστας) ἐνενή(κοντα)]
ἕξ. Ἐγρ(άφη) μ(ηνὶ) Αὐγού(στῳ) ἰνδ(ικτίον)ο(ς) γ,
κ(α)τ' Ἄραβ(ας) ἔτους νε, χειρὶ Στε̣φ[άνου]
Μαϊ[ο]υμιτ( ). Ὅ(λου)· (2nd hand) σί(του)
μ(όδιοι) ϛ, ἐλαίο(υ) (ξέσται) ϛ. //

[Seal.]

Arabic, 2 lines.

Ὅ(λου)· σίτ(ου) μό(διοι)ϛ, ἐλαίο(υ) (ξέσται)ϛ.

One Arabic word on the verso.

3. ζαῖδ, ρ'αγαβ. 4. ἰνδ°/; so too l. 5. αρ'αβ. 6. μαῖ[ο]υμι^{τ}.

3. Ζαιδ: Zaid. Σ[ζαβαν]: or Σ[αβαν], leaving out the ζ (*cf.* Σααραειν for Shahrain in 1); but in the Aphrodito papyri Sharīk is represented by Σζερικ. The Arabic name is Sha'bān.

5f. Στεφ[άνου] Μαϊ[ο]υμιτ( ): *cf.* 6, 7, and see too 5, 9, Γεωργίου Μαϊουμιτ( ). The hand appears to be the same as that of 6, and though the space is not very large for ανο^{υ} the ου may have been written as a monogram. The stroke over the ι (ῖ), which is equivalent to the diaeresis (ϊ), shows that μαι was a dissyllable.

7. Probably in the same hand as the recapitulation in l. 6 (hand 2).

3. October, A.D. 675.

37.7 cm. by 16.2 cm. Damaged in places.

Arabic, 10 lines.

Ἐν ὀνόμα(τι) τοῦ θεοῦ· Ἀλλααρεθ β(εν) Ἀβδ τοῖ(ς)
ἀπὸ
Νεστάνων κλήμα(τος) Ἐλούση(ς) χώρ(ας) Γάζης.
Π̣α̣ρ(άσ)χ(ετε) τ̣(α)χ(έως)
Ἀμωρ β(εν) Καις τῶ(ν) Β(ανι) Σααδ β(εν) Μαλεχ
(ὑπὲρ) μη(νῶν) β [Σζαουαλ?]
(καὶ) Δουλκ(α)δ(α) σίτ(ου) μο(δίους) τριακοσίους
δέκα, ἐλα(ίου) (ξέστας)
τριακοσίους δέκα. Ἐγρ(άφη) μ(ηνὶ) Ὀκτω(βρίῳ)
ἰνδ(ικτίον)ο(ς) δ', κ(α)τ' Ἄραβ(ας) ἔτους νε,
χειρὶ Θεοδώρου Ἰωά(ννου). (2nd hand) Ὅ(λου)·
σί(του) μ(όδιοι) τι, ἐλα(ίου) (ξέσται) τι.

[Seal.]

Arabic, 2 lines.

(3rd hand?) Ὅ(λου)· σί(του) μ(όδιοι) τι, ἐλαί(ου)
(ξέσται) τι.

2. νεστανων a correction, a previous name having been washed out. l. κλίματος.

3. Ἀμωρ β(εν) Καις: 'Amr ibn Ḳais. [Σζαουαλ?]: or Σαουαλ (*cf.* the note on 2, 3); i.e. Shawwāl.

4. τριακοσιους δεκα a correction (under the δ of δεκα are traces of τ). So too in l. 5. τι in all places in ll. 6, 7 seems also to be a correction.

4. October, A.D. 675.

31 cm. by 16.7 cm. Imperfect at the top and damaged in places.

Arabic, 4 lines.

Ἐν ὀνόμ(ατι) τοῦ θεοῦ πα(ρὰ?)
Ἀλλααρεθ β(εν) Ἀβδ τοῖ(ς) ἀπὸ Νεστ[άνων]
κλίμα(τος) Ἐλούση[ς] χ̣ώ̣ρ(ας) Γ̣ά̣ζ̣η̣[ς]. Π̣(αράσ)-
χ(ετε) [τ(α)χ(έως) . . . . . .]
τῶ(ν) Β̣(ανι) Σααδ β(εν) Μαλεχ (ὑπὲρ) μη(νῶν) β
Ἀλ[μου(αρραμ) (καὶ) Σαφ(αρ)?]
σίτ(ου) μ(ο)δ(ίους) ἐνενήκοντα ἕξ, ἐλαί[ου] ξ(έστας)
ἐνεν[ήκοντα ἕξ.]
Ἐγρά(φη) μη(νὶ) Ὀκτω(βρίῳ) ἰνδ(ικτίον)ο(ς) δ,
κ(α)τ' Ἄραβ(ας) ἔτους νε, χειρὶ
Προκοπίου. Ὅ(λου)· σίτ(ου) μ(ό)δ(ιοι)ϛ, ἐλαί-
(ου) (ξέσται)ϛ. . .

[Seal.]

Arabic, 2 lines.

(2nd hand) Ὄ(λου)· σίτ(ου) μ(όδιοι)ϛϛ, ἐλαί(ου) (ξέσται) ϛϛ.

1. πα(ρά?): this does not occur elsewhere, but the $\overline{\pi}$ is quite clear, and it does not appear what else it can represent; παρά is after all not unnatural. Or was π^{α} written prematurely for πα(ράσχετε)? No attempt has however been made to delete it.

4. μη(νῶν) β κτλ.: the β is by no means certain, still less what follows, but all the dotted letters are perfectly possible and indeed not unlikely; and since 3 is a requisition for Shawwāl and Dhu'l-ḳa'dah dated in October of the same year it is natural to find here one for the following two months, Al-Muḥarram and Ṣafar.

7. The character at the end is obscure. It is in form rather like a gothic *a* (a) with a tail on the right, through which are two straight oblique strokes. The only parallel is Є, 7, where the shape is rather different, but the same word may well be intended. It is hardly possible to take it as μ(όνοι). Is it merely, in both cases, a scribal mark? The recapitulation here is in the same ink as the rest and in a hand of the same general character, but it is not certain that it was really written by Procopius.

5. February, A.D. 676.

34.3 cm. by 16.7 cm. Imperfect at the top and damaged on the right.

Arabic, 6 lines.

Ἐν ὀνόμ(ατι) τοῦ θεοῦ· Ἀλααρ(ϵ)θ β(ϵν) Ἀβδ τοῖ(ς) ἀπὸ .....[

κλή(ματος) Συκομάζ(ων) χώρ(ας) Γάζ(ης). Π(α)ρ-(άσχετε) τ(α)χ(έως) Ἀβδελλα β(ϵν) Ἀλḳαμα

τῶν Β(ανι) Σααδ β(ϵν) Ζηρ (ὑπὲρ) μη(νῶν) β Σααρειν Ῥαβι (ὑπὲρ) λοι[π(άδων)]

ἰνδ(ικτίον)ο(ς) δ σίτ(ου) μ(ο)δ(ίους) διακοσίους ἑβδομήκοντα ἐννέα,

ἐλαί(ου) (ξέστας) διακοσίους ἑβδομήκοντα ἐννέα,

(ὑπὲρ) τι(μῆς) σίτ(ου) μ(ο)δ(ίων) διακοσίω[ν] ἑβδομήκοντα ἐνν[έα],

ἐλαίο(υ) (ξεστῶν) διαḳο̣σίων ἑβδομήκοντα ἐν[νέα],

νο(μίσματα) δεκαόκτω δίμοιρον. Ἐγρ(άφη) μ(ηνὶ) Φεβρου(αρίῳ) ἰ[νδ(ικτίον)ο(ς) δ],

κ(α)τ' Ἀραβα(ς) ἔτους νϛ, χειρὶ Γεωργίου Μαϊου-μιτ( ).

Ὄ(λου)· σίτ(ου) μ(ό)δ(ιοι) σοθ, ἐλαίο(υ) (ξέσται) σοθ, (καὶ) (ὑπὲρ) τι(μῆς) σίτ(ου) μ(ο)δ(ίων) σοθ, ἐλαίρ(υ) (ξέστῶν) σρ[θ]

νο(μίσματα) ιηβ/.

[Seal.]

Arabic, 3 lines.

Ὄ(λου)· σίτ(ου) μ(ό)δ(ιοι) σοθ, ἐλαίο(υ) (ξέσται) σοθ, (καὶ) (υπὲρ) τι(μῆς) Arabic.

σίτ(ου) μ(ο)δ(ίων) σοθ, ἐλαί(ου) (ξεστῶν) σοθ, νο(μίσματα) ιηβ/.

1. The second part of the α of αβδ has been remade. 2. 1. κλί(ματος). 4. ἰνδ°/. ϵννεα perhaps written over a previous number, which had been washed out. 5. The first stroke of κ in διακοσιους remade. 6. The first four words perhaps written over a deletion. 9. μαΐουμι̣τ. 11. ἰηβ/; so too in l. 13.

In the name of God. Al-Hārith b. 'Abd to the people of . . . in the region of Sycomaza, province of Gaza. Pay quickly to 'Abd Allāh b. 'Alḳamah of the Bani Sa'd b. Zīr for the two months the two Rabī's, for arrears of the 4th indiction, two hundred and seventy-nine *modii* of wheat, two hundred and seventy-nine *sextarii* of oil, for the price of two hundred and seventy-nine *modii* of wheat and two hundred and seventy-nine *sextarii* of oil eighteen and two-thirds *solidi*. Written in the month of February of the 4th indiction, year 56 according to the Arabs, by the hand of George son of Maïoumit-( ). Total: 279 *modii* of wheat, 279 *sextarii* of oil, and for the price of 279 *modii* of wheat and 279 *sextarii* of oil 18⅔ solidi.

1. The characters at the end, after ἀπὸ, look like α̣τ/ (or θ̣τ/) αβ.[. The second α at least seems certain.

3ff. The meaning here is by no means apparent. The indiction number (lost in the lacuna at the end of l. 8) should be 4, as there read, for the year of the Hegira is 56, which began 25 Nov. 675; a 4th indiction began 1 Sept. of the same year, and *cf.* the next *entagion*, dated in February, ind. 5, year 57. It seems strange to be collecting arrears of the current indiction, and one would have expected τῆς παρούσης to be inserted. Since however the Arab year, by which the budget was presumably estimated, did not begin till 25 Nov., nearly three months after the beginning of the indiction, these arrears, though of the current indiction, might be from the past year of the Hegira, and this may account for the omission of τῆς παρούσης.

The question remains however: what was being collected? In other words, is the payment now demanded to rank as that for the two Rabī's, and what is the relation between the payment in kind and the *adaeratio*? I suggest, but with all reserve, that the payment in kind was for the early months of the indiction, the concluding months of year 55, which, not having been collected at the time, had been debited to the period of the two Rabī's, and that, as the delivery of so much corn and oil at one time might cause a local shortage, the ordinary payment for the Rabī's was commuted in money, at the rate of 18⅔ *solidi*. It is an objection to this view that (καὶ) would be expected before (ὑπὲρ) λοιπ(άδων). For other possible explanations see the introduction (above, p. 537).

9. Μαϊουμι̣τ( ): see 2, 5, note.

12–3. This may be, but is not certainly, in the hand of George.

6. February, A.D. 677.

26 cm. by 19 cm. Imperfect at the top and on the left.

Arabic, 4 lines.

Ἐν ὀνόμ(ατι) τοῦ θεοῦ· Ἀλααρϵθ Arabic.

[β(εν) Ἀβδ] τοῖ(ς) ἀπὸ Νεστάνων κλίμα(τος)
Ἑλούση(ς) χώρ(ας) Γάζης. Π(αράσ)χ(ετε)
[τ(α)χ(έως) Ἀβ]ββᾶ Ταβλεαῖ ἀμ' ἑταίρῳ Γερρᾳ ἀπὸ
5 [.....] (ὑπὲρ) μη(νῶν) β̄ Σααραειν Ῥαβη σίτ(ου)
μ(οδίους) ἐνενήκο(ντα),
[ἐλαί(ου) ξ(έστας)] ἐνενήκοντα. Ἐγρ(άφη) μ(ηνὶ)
Φεβρ(ουαρί)ῳ ἰνδ(ικτίον)ο(ς) ϵ, κ(α)τ' Ἄρα(βας)
ἔτου(ς) νϛ,
[χειρὶ Στ]εφάνου Μαϊουμιτ( ). (2nd hand)
Ὅ(λου)· σίτ(ου) μ(όδιοι)ς, ἐλαί(ου) (ξέσται)
ς. ..//

[Seal.]

Arabic, 1 line.

Ὅ(λου)· σίτ(ου) μ(όδιοι)ς, ἐλαί(ου) (ξέσται)ς. ///

3. ταβλεαῖ. 6. ἰνδ°/. 7. μαϊουμι^{τ}/.

3. The only case in which the messenger is not an Arab. Here he is clearly a Christian, though the readings in this line are not free from doubt. At the beginning βα seems certain, but as the stroke before β is somewhat high in the line it is possible that Α]βα (with one β) should be read. ταβλεαῖ (the ῖ suggests that ι forms a separate syllable; hence Ταβλεαῖ) can hardly be doubted, and αμεταιρ^{ω}, which follows, certainly suggests ἄμ' followed by ἑταίρῳ (the ρ^{ω} naturally suggests ρων, but only one man is mentioned and cf. απ^{ο} for ἀπό). It is not necessary to correct to ἑτέρῳ. After γερρα, α is very probable; the letter following looks like the bottom of π, though there is no trace of the top stroke (which may however have disappeared in the fold of the papyrus). Hence ἀπὸ is the likeliest reading. It should be added that τ^{χ}αβ is distinctly little for the lacuna; perhaps therefore, unless there was a space, βα is part of a personal name, Ταβλεαῖ being the patronymic; or, if Ἀβ]ββᾶ be read, a very short name may have preceded. The space is slightly larger than in l. 5 and larger than that in l. 6 by 4 letters.

7. For the symbol at the end of the line cf. 4, 7. Here the character suggests, first, a small *s*-shaped stroke, like the symbol for καί, and then a large roughly formed capital *B*, through which are two long oblique strokes.

7. Date lost.

26.5 cm. by 18.2 cm. Much defaced by rubbing. Perhaps imperfect at the foot; but see note on l. 7.

Arabic, 8(?) lines, very indistinct.

Ἐν ὀνόμ(ατι) τοῦ θεοῦ· .σσαᾳ β(εν) Μαλεχ Arabic.
τοῖ(ς) ἀπὸ Νεστάνων κλή(ματος) Ἑ{λ}λούσης
χώρ(ας) Γάζης. Π(αράσ)χ(ετε)
[τ(α)]χ(έως) Ναυφαλ β(εν) Σαχαῦ τῶ(ν) Β(ανι)
Αὐφ β(εν) Ἀγια σί(του) μ(οδίους) διακοσίους
ἑ[βδο]μή[κον]τ[α, ἐ]λ[α]ι[(ου)] (ξέσταs) [δ]ι[ακοσίους.
Ἐγράφη μη(νὶ) κτλ.]
5 χειρὶ Εὐλαίου rest of line almost entirely defaced.

[Seal.]

. . . . . (γίνεται) σο.

Arabic, 1 line.

Ἐν .....αυ^{τ}.. Νεστάνων κλή(ματος)
Ἑ{λ}λούσης

2. 1. κλίματος; so too l. 7. 3. αν of σαχαν apparently a correction. 4, 5. The ends of these lines almost wholly defaced.

1. .σσαᾳ: I have failed to arrive at a satisfactory reading of this name. Neither ασσαν nor ασσαδ seems possible. Mr. Fulton suggested ισσαα ('Isa), which I adopted for a time, but a later examination with a magnifying glass convinces me that the first letter can hardly be ι; it looks more like α.

3. Ναυφαλ β(εν) Σαχαν: Naufal b. Sakan.

Αὐφ β(εν) Ἀγια: the first name is 'Auf. It has not been possible to identify the second, nor is the reading certain; ωια is as easily to be read as ανια, but neither is a recognizable Arab name.

6. It is by no means certain that anything was written at the beginning of this line, but there are some black marks which suggest ink.

7. This line is most puzzling. The ἐν at the beginning suggests that it is another order, the reading then being ἐν ὀνόματι τοῦ θεοῦ, but it is hardly possible to get this from the tops of letters, which are all that remain, and Νεστάνων κτλ. comes much too close to the beginning for the Governor's name to have occurred before it. αυ^{τ} suggests ὁ αὐτός, which seems abstractly possible if two *entagia* were written on one sheet; but it is hard to find ο before αυ^{τ}: the letter immediately before it looks like τ, so perhaps τ(οῖς) αὐτ(οῖς). But τοῖς αὐτοῖς [ἀπὸ] Νεστάνων is hardly credible. Since this lower portion of the papyrus, containing the recapitulation of the amount, was, as usual, rolled up and sealed, we may suppose that the clerk, charged with the duty of writing a series of documents, wrote them on a long roll, subsequently cutting off each individual piece as required, but by a blunder divided the papyrus in this case too low down, so taking in part of the first line of the following document. Or alternatively the one line partially visible may have been a draft or pen trial which the clerk accidentally left at the bottom of the sheet.

APPENDIX

Official letter. January–August, A.D. 672.

18.4 cm. by 12.5 cm. Much damaged and imperfect on the left.

The papyrus here published was sent to me, as explained in the introduction (p. 538), under the impression that it was an *entagion*. This was however an error. Not only has it no Arabic text, though there is a blank space of nearly 5 cm. at the top, and no recapitulation at the foot (the papyrus, though imperfect on the left, seems to be complete in height, and there would therefore be no room for the recapitulation and seal), not only are the formulae quite different from those of the *entagia*, but, what is quite decisive, the hand is of the sloping type used for letters, not of the minuscule kind employed in communications to a community; see the introduction, p. 533.

The date is earlier than that seen in the surviving *entagia*, viz. the fifteenth indiction and the fifty-second year of the Hegira. A first indiction began on the 1st September, A.D. 672; the 52nd year began on the 8th January and ended on the 26th December of the same year. Thus the document was written between the 8th January and the 1st September, 672. It is clearly a letter, addressed to a plurality of persons (perhaps the local officials?), apparently with reference to tax payments, but little beyond this can be determined owing to the loss of the left side and the poor preservation of what remains. Every line is damaged, whether by holes in the papyrus or by rubbing, so that many letters are preserved only in part. Down- and up-strokes, which in several cases are all that remain, are ambiguous evidence, and similarity in the formation of such letters as π and ν introduces a further element of uncertainty. Nevertheless it is perhaps just worth while, for the sake of completeness, to publish this text also. There is no evidence for determining the amount lost on the left. If the names of both writer and recipients occurred in l. 1 a considerable space is required, but it is conceivable that only the name of the writer was given there and that those of the recipients followed ὑμᾶς. This however adds to the difficulty of finding any restoration of l. 3, if the readings of the visible remains are correct. In l. 7 only the name of the scribe is required, but very likely his patronymic was given, just possibly also a title like χαρτουλαρίου. It must be emphasized that many of the readings are very dubious.

ἐγράψα]μεν πρὸς ὑμᾶς
]με ἅπερ ἀπὸ τῆς σαφιας
] προφῆτ[ο]υ· δεῖ ἴσα γὰρ παρασχεῖν
].[..]ε[.]χα καὶ ο[ὐ] δῖ τὸν ἕως τοῦ
5].ς ἀπερχόμεν[α] καὶ ἐρχόμενα
μη(νὸς) .....].ου ἰ(ν)δ(ικτίονος) ιε, κ(ατ') Ἀ[ραβα]ς ἔτου(ς) νβ, χειρὶ
]ου. //

4. l. δεῖ. τῶ. 7.]ῶ.

2.]με: the space after this (filled by the artificially lengthened cross-stroke of ε) may be either accidental or intentional; so too in l. 5. If intentional, it is for punctuation, and ἅπερ may perhaps begin a sentence; if accidental, it is possible that ἅπερ is governed by ἐγράψαμεν, "we have written to you what. . . ."

ἀπὸ: possibly ὑπὸ, but ἀπὸ is slightly more probable. Σοφίας (a name) cannot be read.

3. προφῆτ[ο]υ: the ρ is all but certain, of π very little remains, η and τ are inferred from up- and down-strokes, ο from the visible stroke above the line which represents υ (ὁ). If the reading is correct it is presumably a reference to Mahomet, perhaps to a saying in the Koran.

δεῖ κτλ.: the γὰρ would be expected before, not after, ἴσα, but I have failed to find any other reading than δει ισα. The ι of ισα is very long, whereas in σαφιας (the only other ι not ligatured) it is short, but the long iota is quite common in the Ḳurrah letters, the hand of which is closely similar to this.

4. At the beginning ϕλια might be read for ε[.]χα. The clause beginning with καὶ (a probable reading) is puzzling, but to read διτον as the end of a word creates insoluble difficulties, and something like (e.g.) τὸν ἕως τοῦ νῦν λόγον seems possible enough. Mr. C. H. Roberts, to whom I showed my transcript, asked me if I thought it possible that ll. 3–5 can contain an allusion to the parable of the labourers in the vineyard (Matthew, xx.1–16). The idea is tempting but, I fear, impossible. The writer would then be a Christian; and it is most unlikely that a Christian in a (presumably) private letter would date by the Hegira. The date and the χειρὶ κτλ. make it all but certain that this is an official letter, and in that case the writer is most probably an Arab. The hand closely resembles those of the Aphrodito papyri and strongly suggests a clerk in government service.

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